R.

Journal

of

THE ROYAL AERONAUTICAL SOCIETY

APRIL 1954

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LEONARDO DA VINCI'S FLYING MACHINE

IT took man three centuries to rediscover, after Leonardo da Vinci, the principles of the screw, the parachute, the submarine, the motor car and the torpedo. It would take a little longer to explain some of the other fantastic devices with which the great Renaissance engineer, artist and boffin filled his copybooks. Crammed with scribbled notes and mysterious sketches, they contain diagrams of gliders, flapping wings, gremlins, and helicopters with great helical screws. Leonardo was the first to study the flight of birds with a view to mechanical imitation. Simultaneously he was painting a lady called Mona Lisa, whose long-suffering smile may well have been due to the artist's habit of flinging down his palette and dashing to the window to observe the behaviour of sparrows' wings under load.

His parachute, another novelty, was a stiffened linen tent underslung with leather and cords. Records suggest that it didn't handle any too well and it is impossible to tell from Mona Lisa's expression whether she hoped it would open or not.

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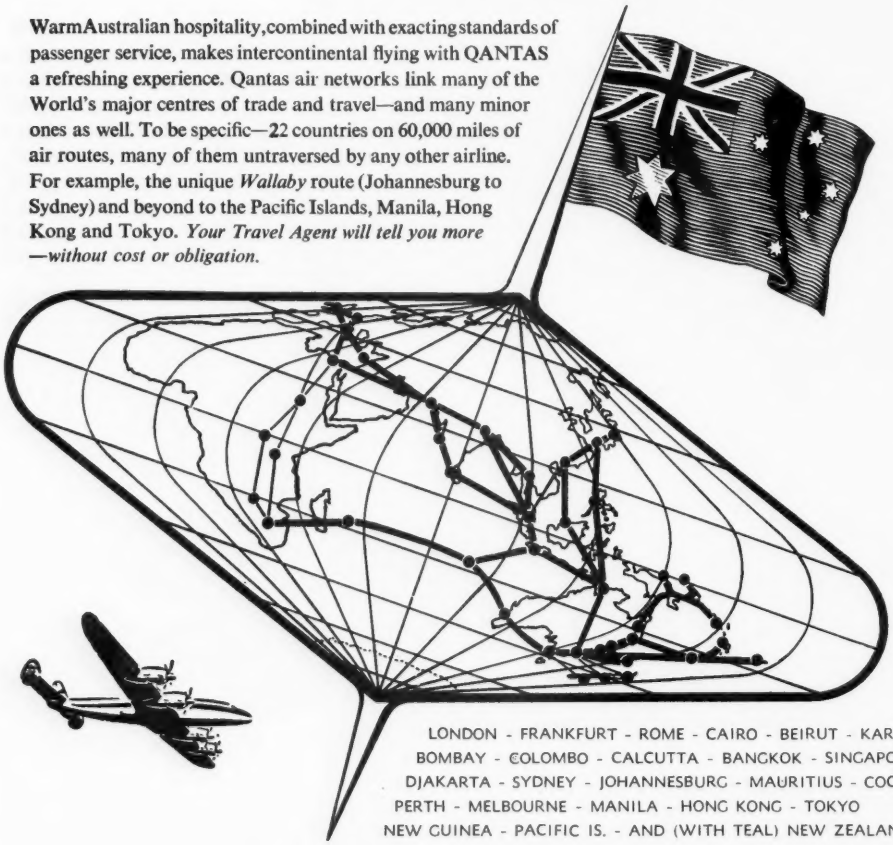

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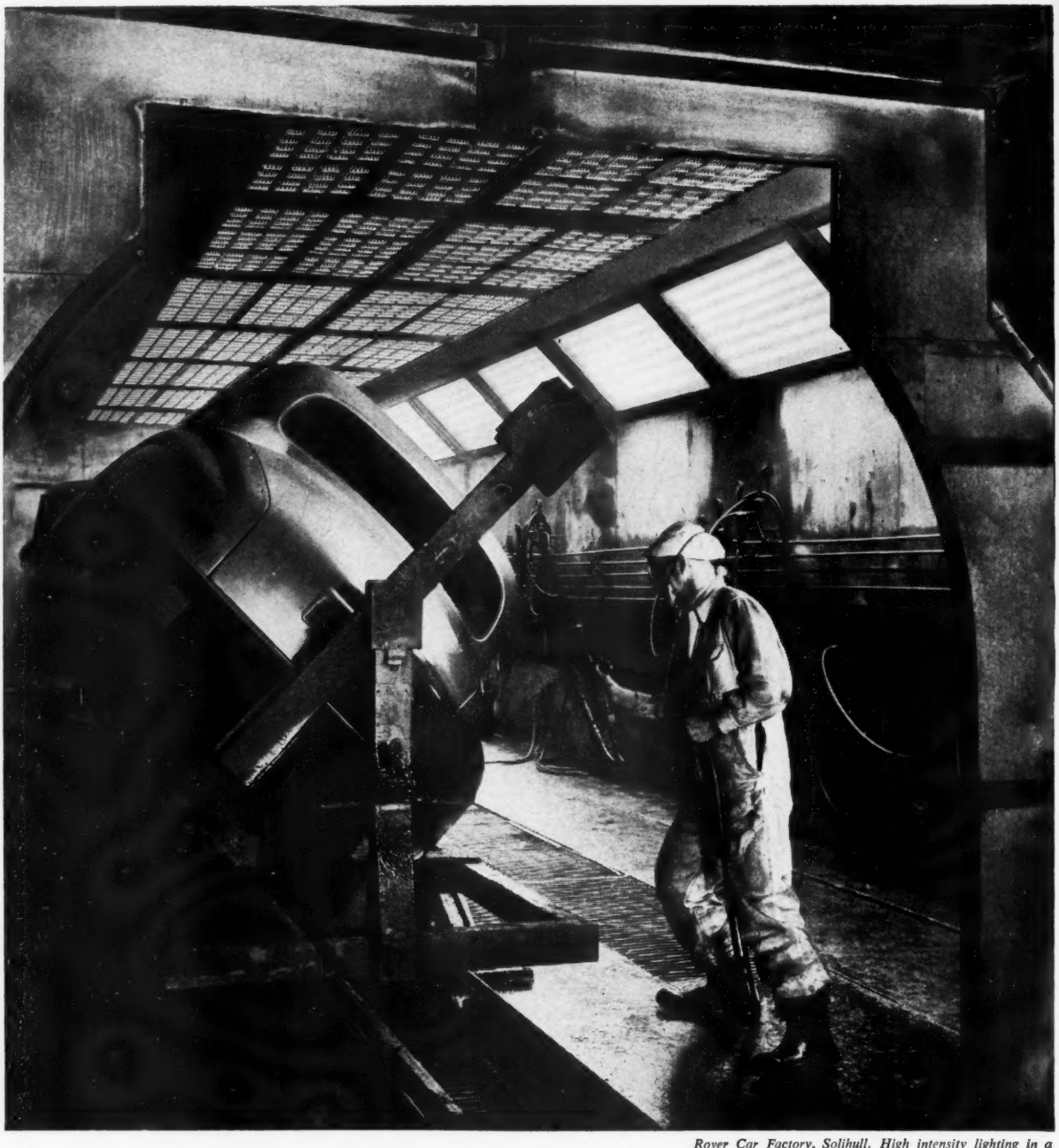

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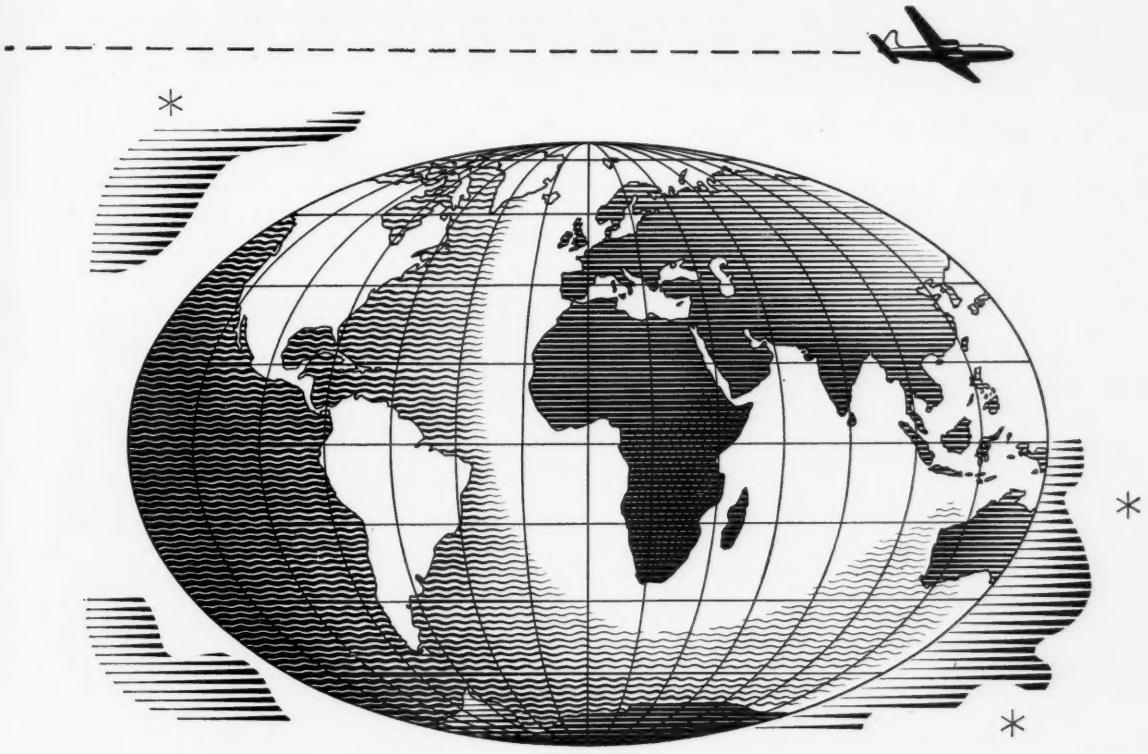

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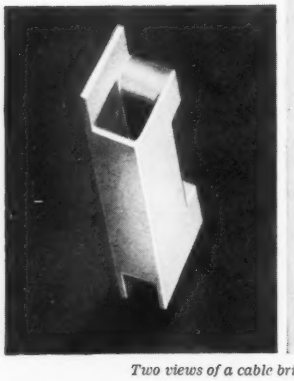

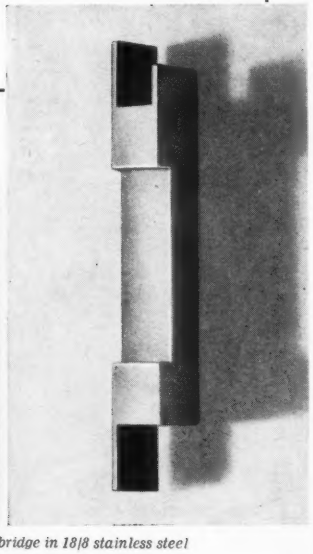

Two views of a cable bridge in 18/8 stainless steel

Trip lever in 18/8 stainless steel

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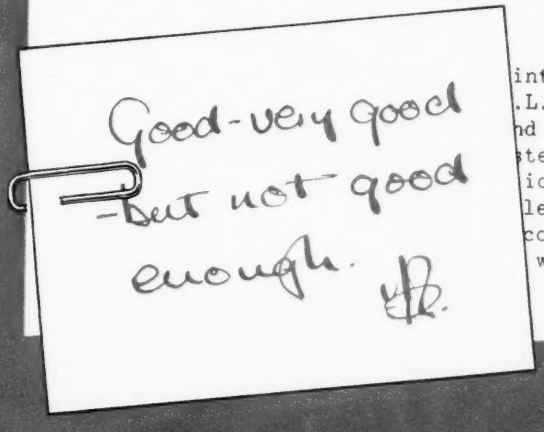

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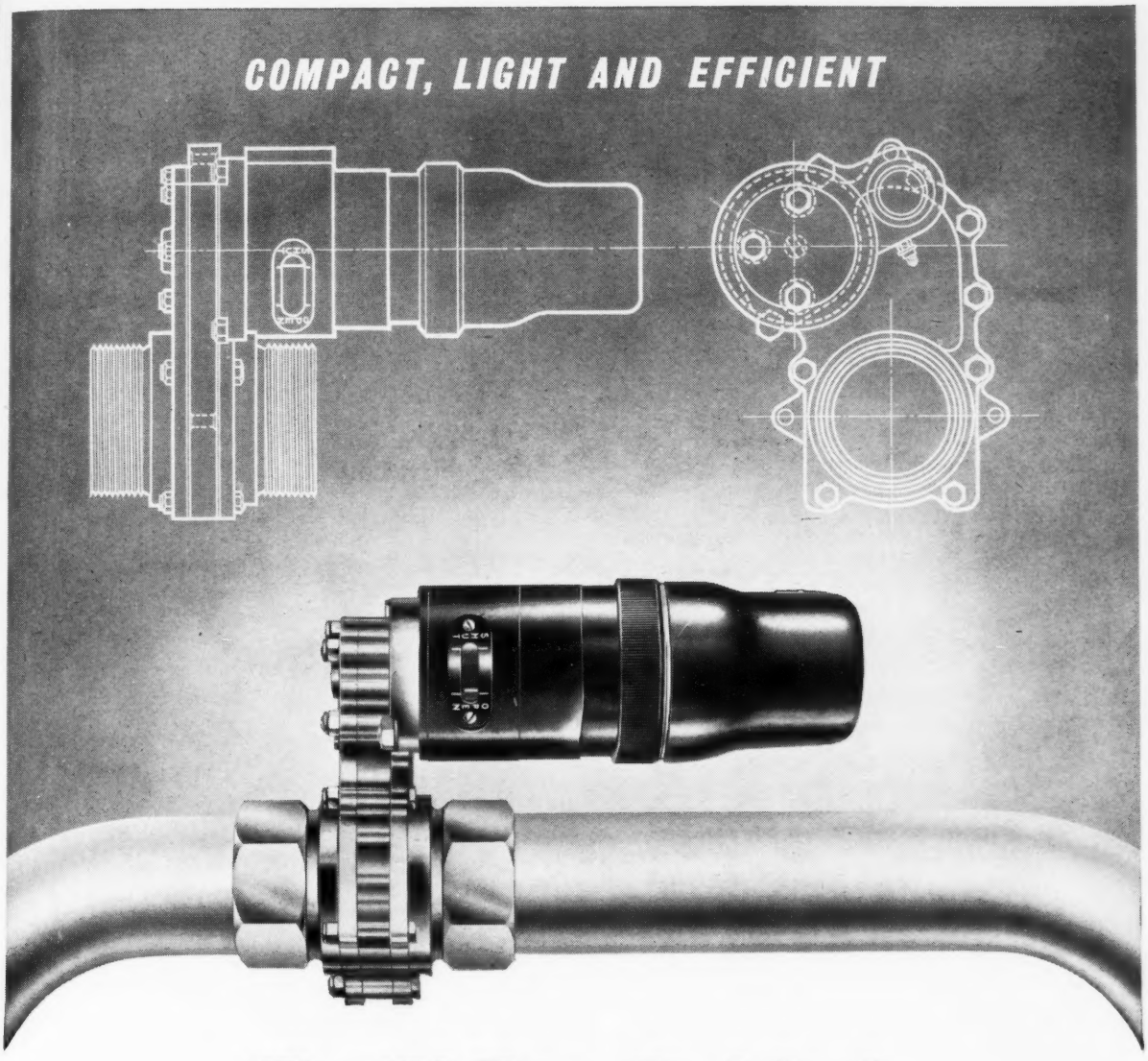

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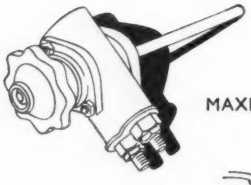

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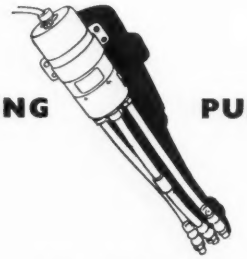

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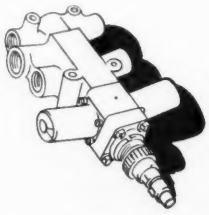

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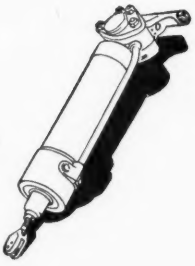

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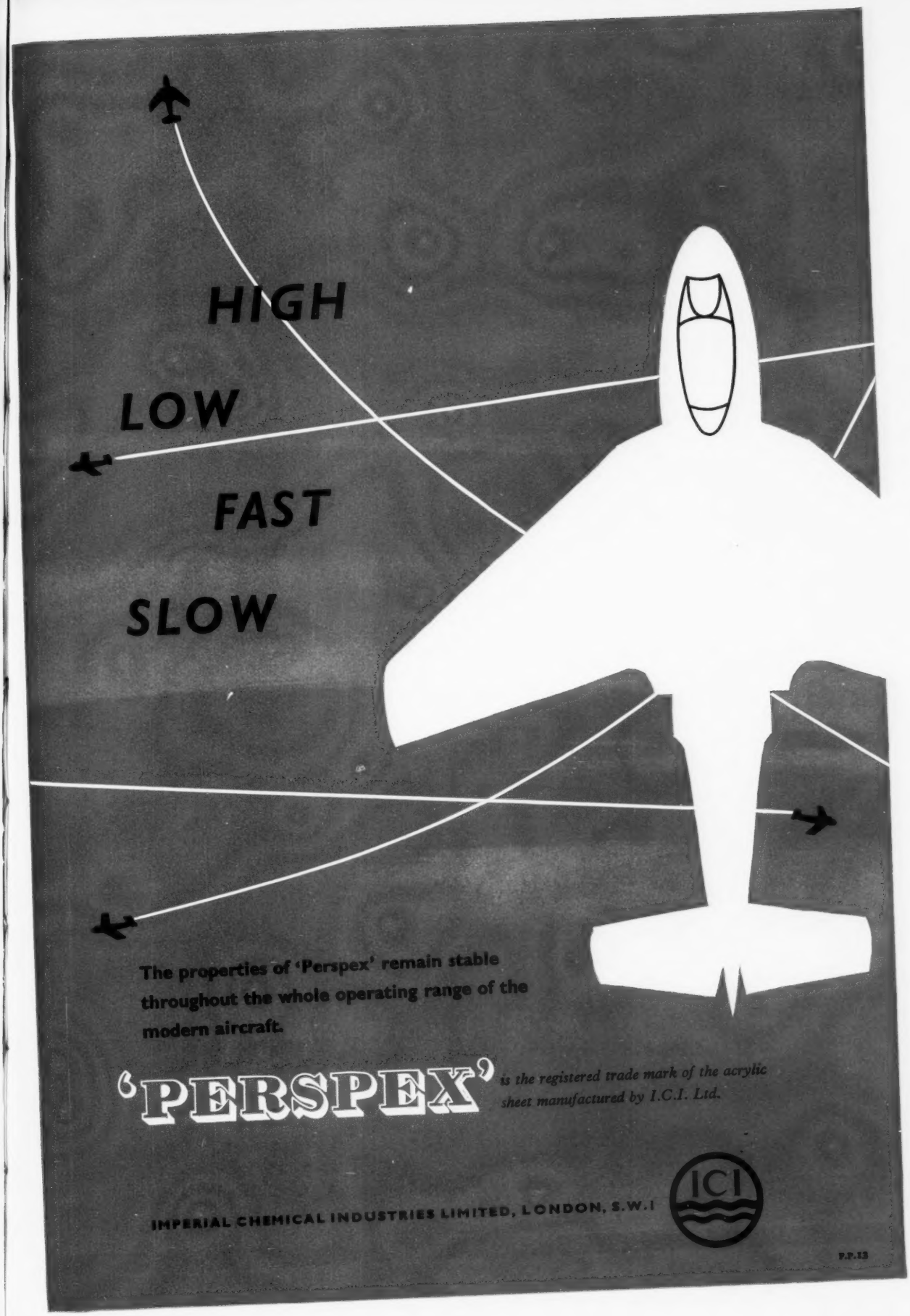

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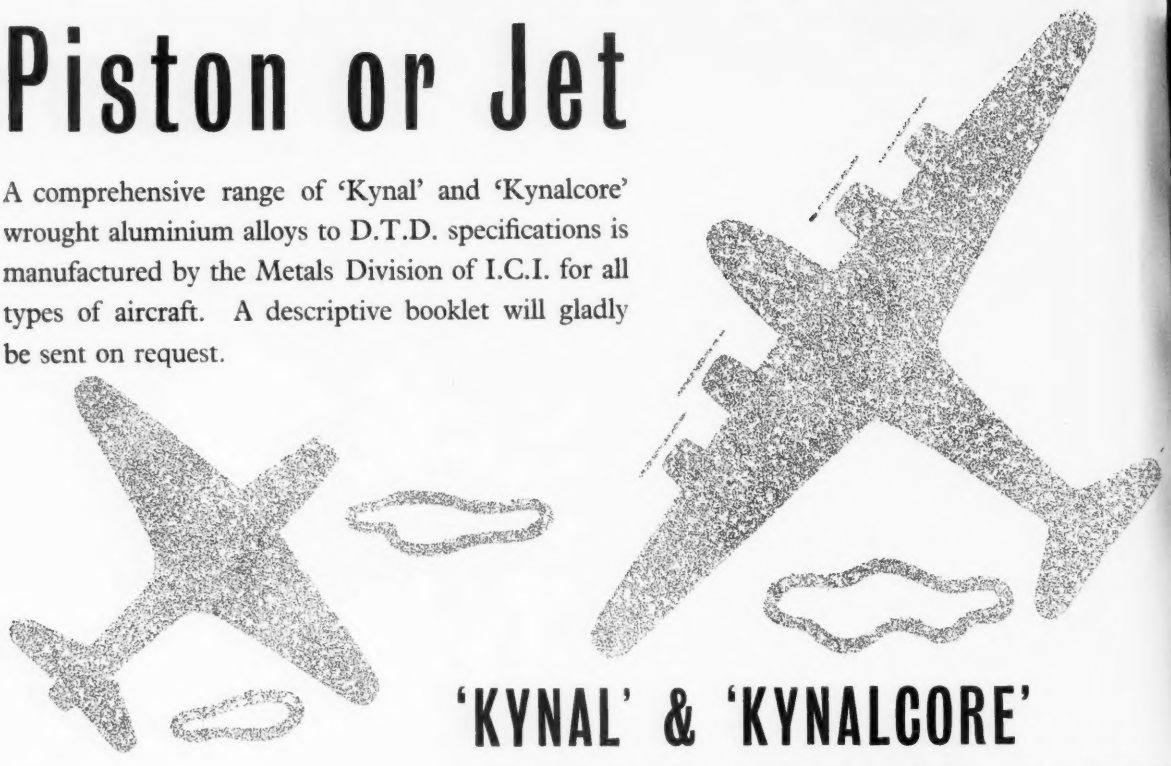

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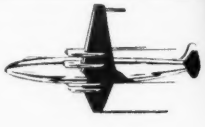

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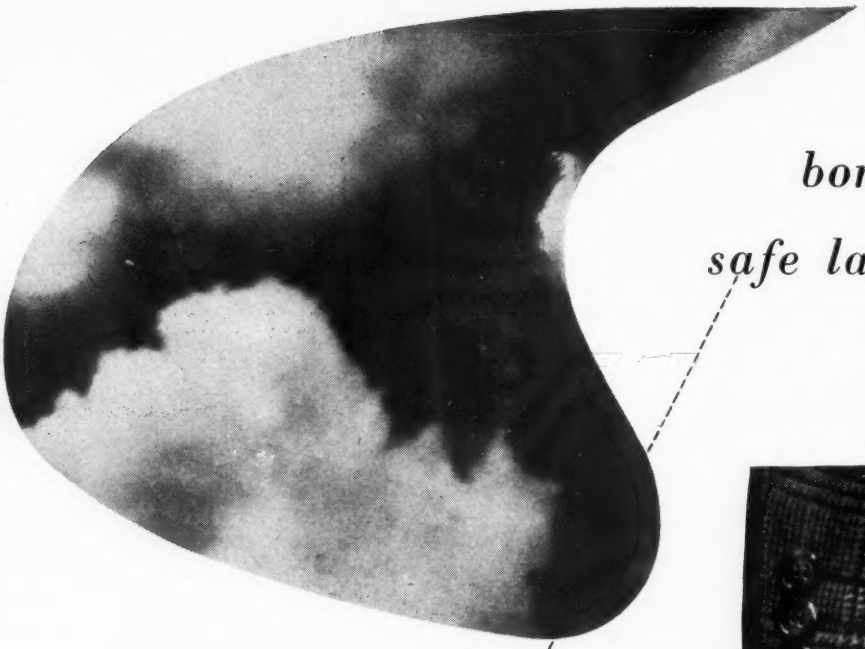

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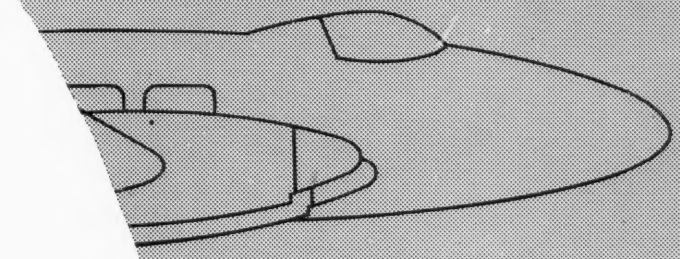

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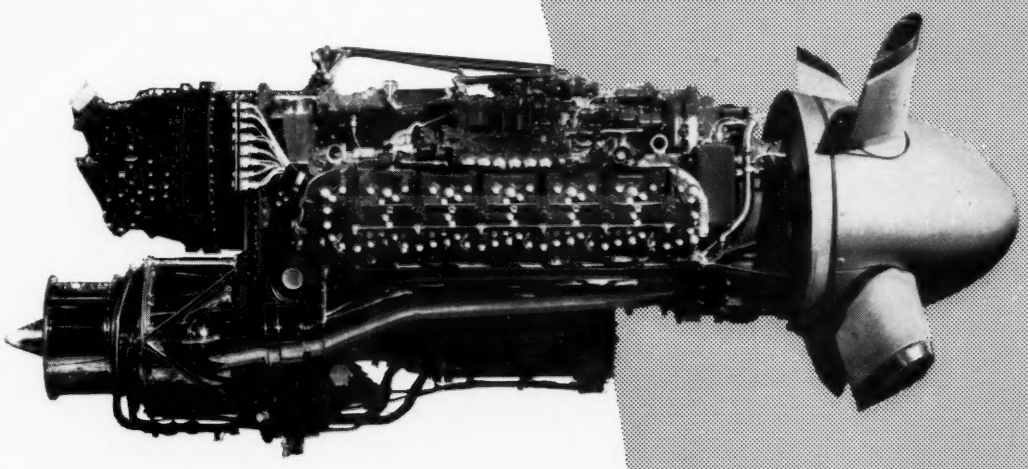

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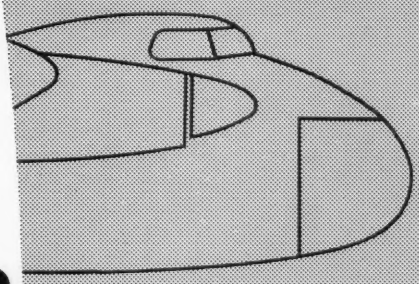

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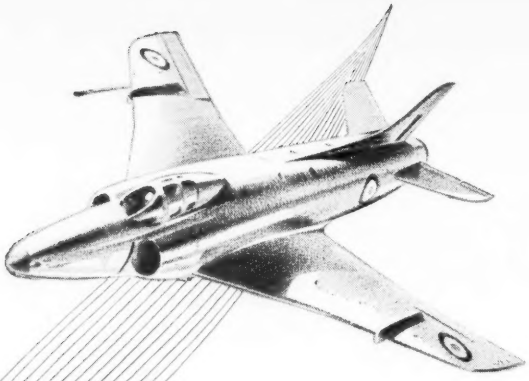

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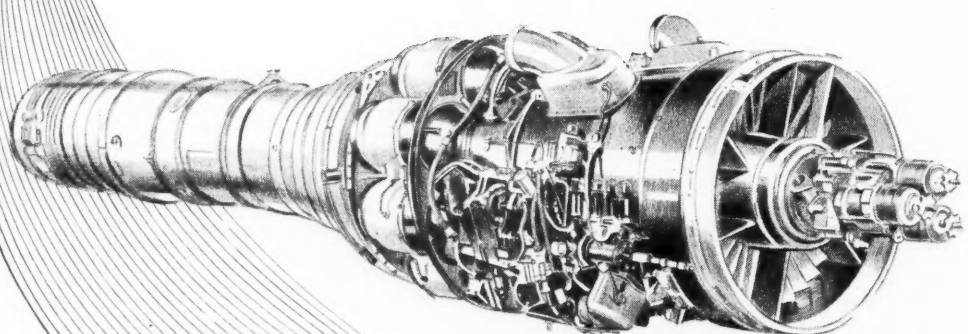

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YEOVIL
Hon. Secretary: L. A. LANSDOWN, A.F.R.Ae.S.,
Westland Aircraft Ltd., Yeovil.

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Annual General Meeting, 6th May 1954

Notice is hereby given that the Annual General Meeting of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Thursday 6th May, at 5.30 p.m. in the offices of the Society, 4 Hamilton Place, London, W.1.

Agenda

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheets and Income and Expenditure Accounts of The Royal Aeronautical Society and Aeronautical Trusts Limited for the year ended 31st December 1953.
3. To receive the names of those elected to Council for the years 1954-57.
4. To announce the names of Fellows elected by the Council in accordance with By-Law 4.
5. To appoint the Auditors for the year 1954.
6. Any other business.

By Order of the Council
A. M. Ballantyne,
Secretary.

NOTE.—In accordance with the By-Laws any member whose subscription has not been paid before the first day of April is not entitled to vote.

Light refreshments will be served after the meeting.

Representatives on Other Bodies

The College of Aeronautics

Sir Roy Fedden and Sir Harold Roxbee Cox have accepted a further term of office on the Board of Governors of the College of Aeronautics as representatives of the Society.

R.A.E. Technical College Advisory Board

Professor A. R. Collar has been appointed the Society's representative on the Advisory Board of the R.A.E. Technical College. Sir William Farren has been appointed Chairman.

Royal Technical College, Salford

Mr. S. D. Davies has been appointed to represent the Society on the Engineering Advisory Committee of the Royal Technical College, Salford.

The 42nd Wilbur Wright Memorial Lecture

The 42nd Wilbur Wright Memorial Lecture will be held on Thursday 20th May 1954 at the Royal Institution, Albemarle Street, London, W.1, at 6 p.m. (Tea at 5.30 p.m.) The Lecture will be given by Dr. A. E. Russell, B.Sc., F.I.A.S., F.R.Ae.S., on "The Choice of Power Units for Civil Aeroplanes."

Graduates' and Students' Section

A visit has been arranged to Vauxhall Motors Ltd. (Luton, Beds.) on 4th June. Applicants are requested to state their mode of transport, *i.e.* private or public transport, so that party travel can be arranged. Applications should be sent to the Hon. Visits Secretary, D. J. W. Richards at 18 Geneva Road, Kingston, Surrey, as soon as possible.

Garden Party, Sunday 13th June 1954 (2.30 p.m. to 6 p.m.), London Airport, Hounslow, Middlesex

The Society will hold its Annual Garden Party at London Airport on Sunday 13th June 1954.

Tickets for the Garden Party are available only to members of the Society and their guests.

No one will be admitted without a ticket except children under five years of age who will be admitted free.

The prices of tickets are:—

Children (5 years to 15 years)	5s. 0d.
Adults	10s. 0d.

The Nash Collection of Veteran Aircraft recently purchased by the Society will be exhibited for the first time.

The car park will open at 12 noon, and the President will receive members and their guests at 2.30 p.m. There will be no flying programme, but it is possible that flights may be arranged in a transport aircraft.

An application form for tickets with full particulars is being sent to all home members.

Associate Fellowship Examination

The next Associate Fellowship Examination will be held in the Offices of the Society on the 25th, 26th and 27th May 1954. Candidates have been sent full details.

Institute of The Aeronautical Sciences Meeting

The Institute of the Aeronautical Sciences is holding a meeting on "Turbine Powered Air Transportation," from 7th-9th August in Seattle, Washington. Papers are being submitted by several British authors, as well as American, and a tour of the Boeing Plant and inspection of the Boeing Jet Transport Prototype will be included as part of the Programme. The Institute of the Aeronautical Sciences is most anxious to encourage British participation. Further particulars may be obtained from the Secretary, R.Ae.S.

News of Members

Mr. H. G. Conway (*Fellow*) and Mr. E. G. Collinson (*Associate Fellow*) have been awarded jointly the Water Arbitration Prize by the Institution of Mechanical Engineers for their paper "An Introduction to Hydraulic Mechanism Theory." Mr. Conway, who resigned from his post of technical director and chief engineer of the British Messier Company last October, has joined Short Bros. and Harland Ltd., Belfast.

W/Cdr. A. E. Davies, O.B.E. (*Associate Fellow*), ex-2nd Tactical Air Force, is now filling a post in Research and Development (Instruments) at the Ministry of Supply. He was awarded the O.B.E. in the Coronation Honours.

Mr. W. W. W. Downing (*Associate Fellow*) has been appointed Works' Manager of the Gloster Aircraft Company.

Mr. James Hodge (*Associate Fellow*), Senior Consultant of Power Jets (Research and Development) Ltd., is at present in New York as Visiting Professor in Gas Turbines at Columbia University.

Mr. G. R. Nicolson (*Graduate*) has been appointed a Senior Scientific Officer in the Department of the Scientific Advisor to the Air Ministry.

Mr. R. Tourret (*Associate Fellow*) has been appointed a Senior Scientific Officer at The Admiralty Oil Laboratory.

The Aeronautical Quarterly

The Aeronautical Quarterly is again to be published four times a year, beginning with Volume V.

In order to complete a volume in one calendar year the four parts of Volume V will be published approximately as follows:—

Part 1	May 1954	Part 2	July 1954
Part 3	September 1954	Part 4	November 1954

It is regretted that it is necessary to increase subscription rates for non-members. Although costs have risen since *The Aeronautical Quarterly* was first published in May 1949 subscriptions have remained the same.

Beginning with Volume V the price of subscriptions to non-members of the Society will be £3 1s. 0d. including postage and packing.

Price per Part—15s. 3d. including postage and packing.

Prices to members of the Society are still 7s. 9d. per Part and £1 11s. 0d. per subscription (4 Parts) including postage and packing.

Volume IV Part 4 of the Quarterly is now available from the offices of the Society. The contents are as follows:—

The Flow Past Elliptic-nosed Cylinders and Bodies of Revolution in Supersonic Air Streams — *D. W. Holder* and *A. Chinneck*

The Influence of the Exit Velocity Profile on the Noise of a Jet — *Alan Powell*

The Second Order Terms in Two-Dimensional Tunnel Blockage — *L. C. Woods*

Adiabatic One-Dimensional Flow of a Perfect Gas through a Rotating Tube of Uniform Cross Section — *K. Keston* and *S. K. Zaremba*

Apparatus for the Remote Recording of Flow Conditions — *K. W. Todd*

Index to Volume IV

Copies of all issues of *The Aeronautical Quarterly* are still available and subscriptions to all volumes can still be accepted.

Papers will be welcomed on all aeronautical subjects and on the allied sciences.

Overseas Journals

The Editor wishes to thank those members and subscribers resident abroad who returned the post card enclosed with their December 1953 and January 1954 Journals, replying to the question on Journals sent "flat in an envelope" or "rolled and wrapped."

Of the 410 cards received so far, opinion is almost equally divided—except on the effectiveness of the "tear off" strip on which opinion is unanimous!

The comments have been most helpful and interesting, although the varied experience with Journals, even in adjacent districts in Africa and Australia, for example, is amazing.

From this preliminary investigation it looks as if it may be impossible to please everyone but experiments are continuing in the hope of finding a not too expensive compromise. Meanwhile it is hoped that the "tear off" strip is proving more effective.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to: Flight Sergeant Apprentice T. E. Enright of the May 1951 Entry, who obtained the highest marks in the General Studies examination.

Diary

LONDON

April 13th

Section Lecture. Some Aspects of Modern Aircraft Materials. Dr. H. Sutton. 4 Hamilton Place, W.1. 7 p.m.

April 22nd

Main Lecture. Diesel Compound Engines. E. E. Chatterton. At the Institution of Mechanical Engineers, Storey's Gate, S.W.1. 6 p.m. (Tea 5.30 p.m.)

April 27th

Section Lecture. Aerodynamics and Aeroelastic Characteristics of the Crescent Wing. G. H. Lee. In the Library, 4 Hamilton Place, W.1. 7 p.m.

April 29th

Graduates' and Students' Section. Fuselage Structural Design Methods. R. J. Jupe. 4 Hamilton Place, W.1. 7.30.

May 4th

Section Lecture. Propellers for High-Speed Aircraft. G. C. I. Gardiner. In the Library, 4 Hamilton Place, W.1. 7 p.m.

May 20th

The 42nd Wilbur Wright Memorial Lecture. The Choice of Power Units for Civil Aeroplanes. Dr. A. E. Russell. Royal Institution, Albemarle Street, W.1. 6 p.m. (Tea 5.30 p.m.)

BRANCHES

April 14th

Glasgow.—Annual General Meeting. St. Enoch Hotel, 7.30 p.m.

Hatfield.—Discussion Evening. de Havilland Restaurant, Hatfield. 6.15 p.m.

Preston.—Annual General Meeting and Film Show. "Powered Flight—The Story of the Century" and "Rig 20." R.A.F.A. Concert Hall, Preston. 7.30 p.m.

April 15th

Gloucester and Cheltenham.—Annual General Meeting. St. Mary's College, Cheltenham. 7.30 p.m.

April 23rd

Hatfield.—Annual Dinner. de Havilland Restaurant, Hatfield. 6.15 p.m.

April 27th

Merthyr Tydfil.—The Effect of High Temperatures on Aircraft Materials. H. E. Gresham. Vaynor and Pengeryn Grammar School, Cofn Coed. 7.30 p.m.

April 28th

Coventry.—Annual General Meeting and Films. Wine Lodge, Coventry. 7.30 p.m.

Southampton.—Some Recent Developments in Civil Engineering. Dr. A. G. Pugsley. Institute of Education, University of Southampton. 7 p.m.

April 30th

Birmingham.—Aircraft Electrics. R. H. Woodall and J. H. Rea. Birmingham Chamber of Commerce, New Street, Birmingham. 7.30 p.m.

May 3rd

Derby.—Operational Use of Jet-engined Aircraft. Commandant of the R.A.F. College. Welfare Hall, Rolls-Royce. 6.15 p.m.

May 5th

Weybridge.—Annual General Meeting. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

May 12th

Chester.—Annual General Meeting. Grosvenor Hotel, Chester. 7.30 p.m.

Leicester.—The Medical Effect of High Speed and Aerobatic Flying. Squadron Leader R. S. Warrbeck. Leicester College of Technology. 7.15 p.m.

May 19th

Hatfield.—Annual General Meeting and Film Show. de Havilland Restaurant, Hatfield. 6.15 p.m.

Journal Premium Awards

The following Premium Awards have been made for papers and Technical Notes published in the Journal during 1953:—

Dr. P. B. Walker, for his paper on "Design Criterion for Fatigue of Wings." (January 1953.) £15 15s. 0d.

Professor E. J. Richards, for his paper on "Research on Aerodynamic Noise from Jets and Associated Problems." (May 1953.) £15 15s. 0d.

Dr. E. W. Still, for his paper on "Temperature Control of Jet-Engined Aircraft." (February 1953.) £15 15s. 0d.

B. R. Diplock, D. L. Lofts and R. A. Grimston, for their paper on "Liquid Propellant Rocket Motors." (January 1953.) £5 5s. 0d. each.

K. J. Dallison, for his paper on "Stress Analysis of Circular Frames in a Non-Tapering Fuselage." (March 1953.) £15 15s. 0d.

P. S. MacGregor, for his paper on "The Development of Probe and Drogue Refuelling." (August 1953.) £15 15s. 0d.

W. J. D. Annand, for his paper on "The Resistance to Air Flow of Wire Gauges." (March 1953.) £15 15s. 0d.

J. D. Hayhurst, for his paper on "Acoustic Screening by an Experimental Running-up Pen." (January 1953.) £15 15s. 0d.

F. Smith and W. J. D. Hicks, for their paper on "Design of a Simple Electronic Flutter Simulator." (January 1953.) £15 15s. 0d.

L. G. Dawson, for his paper on "The Fluid Mechanics of Detonation Waves." (October 1953.) £15 15s. 0d.

P. B. Benham, for his paper on "Bending Moments in Fuselage Frames obtained by the Photoelastic Method." (November 1953.) £15 15s. 0d.

C. B. Davies, for his paper on "Developing Aviation Fuels and Lubricants." (November 1953.) £15 15s. 0d.

J. Warner and K. J. Heffernan, for their Technical Note on "The Use of Radar to Measure True Air Speed of an Aircraft." (October 1953.) £5 5s. 0d. each.

D. M. Heughan, for his paper on "An Experimental Study of a Symmetrical Aerofoil with a Rear Suction Slot and a Retractable Flap." (October 1953.) £15 15s. 0d.

B. A. Hodson, for his Technical Note on "A Method of Calculating Stresses in a Non-Uniformly Thick Disc subjected to Asymmetric Loads Adapted to a Tabular Computation." (October 1953.) £5.

E. R. Gadd, for his paper on "Fatigue from a Metallurgist's Viewpoint." (September 1953.) £5.

F. M. Owner, for his paper on "Fatigue in Engine Design." (September 1953.) £5.

B. E. Stepenson, for his paper on "Fatigue in Aircraft Design." (September 1953.) £5.

H. L. Cox, for his paper on "Fatigue." (September 1953.) £5.

Acknowledgments

The Council acknowledges with many thanks the gift to the Library of an interesting scrap book presented by Miss Kathleen Gurney. It deals largely with the period 1909-1912 and with Mr. B. R. Moorhouse.

The Council also acknowledges with thanks the gift of books from A. G. Gooch, Esq., *Associate Fellow*, and the return of back numbers of the Journal from K. G. Bergin, Esq., *Associate Fellow;* V. E. Erlebach, Esq., *Associate;* and V. G. Jones, Esq., *Associate Fellow*.

Medals and Prizes for Papers

The following Medals and Prizes have been awarded for papers read before or published by the Society during 1953.

The George Taylor (of Australia) Gold Medal.—Awarded for the most valuable contribution read before, or published by, the Society on Aircraft Design, Manufacture or Operation, to:—

V. A. M. Hunt, *Associate Fellow*, for his paper on "Air Traffic Control Today and Tomorrow." (May 1953 Journal.)

The Simms Gold Medal.—Awarded for the most valuable contribution read before, or published by, the Society on any subject allied to Aeronautics, to:—

E. D. Keen, *Fellow*, for his paper on "Integral Construction—Its Application to Aircraft Design and its effect on Production Methods." (April 1953 Journal.)

The Edward Busk Memorial Prize.—Awarded for the most valuable contribution read before, or published by, the Society on Applied Aerodynamics, to:—

Dr. D. Kuchemann, *Associate Fellow*, for his papers (*i*) "Types of Flow on Swept Wings," (*ii*) The Distribution of Lift over the Surface of Swept Wings." ((*i*) November 1953 Journal and (*ii*) Part III, Volume IV, *The Aeronautical Quarterly*, August 1953.)

The Usborne Memorial Prize.—Awarded for the best contribution to the Society's Publications written by a Graduate or Student on some subject of a Technical nature in connection with Aeronautics, to:—

A. J. Barrett, *Graduate*, for his paper on "Unsymmetrical Bending and Bending Combined with Axial Loading of a Beam of Rectangular Cross Section into the Plastic Range." (August 1953 Journal.)

The Pilcher Memorial Prize.—Awarded for the best paper read by a Graduate or Student during the previous year at any meeting of the Society or its Branches, to:—

J. D. Sibley, for his paper on "An Introduction to the Helicopter" given to the Graduates' and Students' Section on 18th November 1952 and published in the April 1953 Journal.

The Orville Wright Prize.—Awarded for the best contribution received for publication in *The Aeronautical Quarterly* of the Society on some subject of a technical nature, in connection with Aeronautics, awarded jointly to:—

Alan Powell, for his paper "On the Noise Emanating from a Two-Dimensional Jet above the Critical Pressure." (Part II, Volume IV, *The Aeronautical Quarterly*, February 1953) and

G. E. Gadd, for his paper on "Some Aspects of Laminar Boundary Layer Separation in Compressible Flow with no Heat Transfer to the Wall." (Part II, Volume IV, *The Aeronautical Quarterly*, February 1953.)

The Branch Prize.—Awarded for the best paper on an Aeronautical subject read before the Branches and published by the Society, to:—

J. Taylor, for his paper on "Structure Weight" read before the Leicester Branch on 21st November 1952 and published in the October 1953 Journal.

No awards have been made this year for the following:

(*i*) *The Herbert Akroyd Stuart Memorial Prize*, awarded for the most valuable contribution read before, or published by, the Society on Applied Thermodynamics.

(*ii*) *The Royal Aeronautical Society Navigation Prize*, awarded for the best paper on Navigation, including Meteorological Instruments and Test Equipment.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Madras Srinivas Balasubramanian (*from Graduate*)
Jeffrey Laurence Crowder (*from Graduate*)
Hubert John Davies
Kenneth Howard Dickenson (*from Graduate*)
George Francis Keiller Donaldson
David George Dunphy
Raymond William Dyke (*from Graduate*)
Peter John Elmes (*from Graduate*)
Vernon Frederick Gardener (*from Graduate*)
Kenneth Harold Greager
Malcolm Alexander Henderson (*from Associate*)
George Stallwood Henson (*from Student*)
Stanley Frank Hurford
Douglas Royston Darleston Jones (*from Graduate*)
William Henry King (*from Associate*)
David Francis Michell
William Edward Morris (*from Graduate*)
George Edward Preece (*from Graduate*)
Gordon Reynard (*from Graduate*)
Gilbert Frank Satchwell (*ex-Graduate*)
Ronald Owen Scott
John Sutherland (*from Graduate*)
John Herbert Swannell
Priykant Avantilal Vasavada (*from Graduate*)
Kenneth Ronald Welling (*from Student*)
Peter Herbert Stringer Wroe (*from Graduate*)

Associates

Alan Francis Bandidt
William Thomas Harrington
Noel Holman
Cyril Thomas Stedman Manser (*ex-Associate*)
Ernest Edward Thaxter
Roland James Westcott
Raymond Southon Wilkins

Graduates

Robert Colville Aikman (*from Student*)
Derek Harry Boyce
David George Ashley Bridgnell
Dennis James Carey (*from Student*)
Edward George Clegg (*from Student*)
Roy Edgar Clement
Denzil De Villiers (*from Student*)
Anthony Edward Albert Dudman
Keith Emslie
Harry Ronald Harrison (*from Student*)
Donald Reginald Henbest (*from Student*)
John Charles Michael Jones (*from Student*)
Basil Thomas Lewis (*from Student*)
Raymond Lewis (*from Student*)
John David Francis MacNaughton (*from Student*)
George Rene Mortreuil
John Gordon Hedley Pearce (*from Student*)
Arnold Graham Rogers
Robert John Sellars (*from Student*)
Raymond Frederick Smith (*from Student*)
Brian John Van De Water (*from Student*)
Francis Ian Victor Walker (*from Student*)

Students

Eric Gordon Crabtree
Robin Michael Dakin
Antony Day
Michael Gaster
Frederick Brian Goodall
Pillai K. Gopalakrishna
Malcolm Alastair Gray
Gerald William Honey
Eric William Hope
George Hosie
John Lovejoy Johnston
Mahboob Hamidullah Jung
Deep Chand Kohli
Norman Percy George Last
Rhys Barry Lewis
Malcolm Harvey Lock
Michael Edwin Abbott Manning
John Gordon Outram
Michael John Schofield
Roger Ian Sykes
Graham Henry Talmage

Companions

Frank Edward Collins (*from Student*)
Richard Mounteney Hilary
Arthur Francis Winstanley (*from Student*)

Income Tax

In response to numerous inquiries from members with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes.

Ref. H.R.S. 34/C.I. 4420/63.

Dear Sir,

Further to your interview with Mr. Stonely at this office on the 19th July, I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are:—

(*i*) Assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business on: or

(*ii*) Assessable under Schedule E in those cases only in which continual membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,
(Signed) Geo. Wilcock,
Principal Inspector of Taxes.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters). New address (in block letters).
Grade of membership. Old address.

Changes of address must be received *before the 15th of the month in order to be effective for the* Journal for the following month.

Journal Binding

Self-Binder Cases

Self-Binder cases of the "Easibind" type are available from the offices of the Society. These binders are for members who do not have their Journals permanently bound, or who wish to keep their Journals together during the year for binding later.

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The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

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AERONAUTICAL ACOUSTICS

In Particular, Jet Noise

A joint Symposium on "Aeronautical Acoustics—in particular Jet Noise," was held by the Royal Aeronautical Society and the Acoustics Group of the Physical Society at the Institution of Mechanical Engineers, Storey's Gate, S.W.1, on 21st May 1953.

There were four sessions; in each of the first three there were two papers dealing with a particular aspect of the subject, namely, engine, aircraft, and ground noise, and each session was followed by a discussion. The fourth session was devoted to a General Discussion.

MR. N. FLEMING presiding at the first session, on engine noise, expressed the thanks of the Acoustics Group of the Physical Society to the Royal Aeronautical Society, which had borne the entire burden of the arrangements for the meeting.

He continued: The subject of noise produced by aircraft was one to which it was hardly possible to turn a deaf ear! It would be difficult to make any estimate of the relative amounts of noise produced by different industries, but he thought that the Aircraft Industry, in its development work, construction, testing and the operation of aircraft, would stand high in the lists He knew of no more powerful single source of noise than the modern jet engine, which produced noise at a rate of the order of 100 h.p., an amount which, if radiated uniformly in all directions, would be painful at a distance of about 100 ft. and even allowing for the attenuation which took place in transmission to a distance, would interfere with conversation at a distance of 3,000 ft. If the noise were radiated more in one direction than in another, the effect would be even worse in that direction.

During the past few years a good deal of research had been done at the Universities of Southampton and Manchester and at the College of Aeronautics on the mechanism of the production of jet noise, and knowledge of the subject had been advanced very considerably. The research had been helped very much by a mathematical theory put forward by Professor Lighthill.

He had pleasure in introducing the first two lecturers, Professor E. J. Richards (Professor of Aeronautical Engineering, University of Southampton), and Mr. F. B. Greatrex (Rolls-Royce Ltd.), who would talk on "Engine Noise."

ENGINE NOISE

Jet Engine Noise

by

E. J. RICHARDS, M.A., B.Sc., F.R.Ae.S.

(*Professor of Aeronautical Engineering, University of Southampton*)

DURING the past few years, the introduction of the large jet air liner has introduced new noises into the sky which has caused the public to be more aware than ever of the increasing nuisance value of aircraft taking off, landing, or on the ground. Much of this is being blamed unfairly on the jet air liner but the problem in any case remains with us.

For example, recent measurements given before the Society of Automotive Engineers are very revealing; here Baranek plotted the maximum noise levels on the ground when aeroplanes took off with a 5° take-off path. If it is assumed that a noise level of 80 phons is rather like the noise in a very busy street and would definitely interfere with speech, such a noise would occur as far as 2½ miles in the aeroplane path for a Dakota, 4 miles from a Stratocruiser, but 12 miles on a six-engine jet air liner with reheat and 16 miles with supersonic propellers. That is to say it would be necessary to give up talking here each time a jet air liner of this type were to fly from London Airport in this direction.

This figure is pessimistic, as reheat is unlikely to be used until American jet air liners are certificated or are operated in this country (let us take a firm hand on this aspect now); however, as I pointed out in a paper published in the May JOURNAL of the Royal Aeronautical Society*, realistic estimates of the expected noise levels show that we must endeavour to obtain a 15 decibel

*Research on Aerodynamic Noise from Jets and Associated Problems. E. J. RICHARDS, *Journal of the Royal Aeronautical Society*, May 1953.

reduction in flight and a 25 decibel reduction in ground test running in the not too distant future.

Now what are we doing about it? On the propeller side, very little; but on the jet side, quite a lot. This consists of a large amount of theoretical and model work from the Universities of Manchester and Southampton and from the College of Aeronautics, while other work has been done by Mr. Fleming, National Physical Laboratory, by Rolls-Royce, Faireys and Saunders-Roe. As a result of two years' work, it cannot be claimed that noise has been reduced sufficiently (but you will be hearing from Mr. Greatrex the results of his full-scale tests) and work must undoubtedly go on at an accelerated pace; our understanding of the nature of noise formation however has progressed considerably, and is now helping us to devise noise reduction rules for the future.

Briefly, aerodynamic noise from a jet arises from the following three general sources:—

(*a*) Subsonically as a field of acoustic quadrupoles (Mr. Lilley will be mentioning this) which gives rise to noise increasing roughly as V^8, the high frequency noise arising from the high velocity shear and turbulence at the edge of the jet close to the jet nozzle, the low frequency noise arising from the larger burbles into which the fine scale turbulence wraps itself downstream.

(*b*) When a jet is choked, noise still arises from the above but is over-shadowed by a further and more potent source of noise. To understand this latter source, it must be realised that when a jet is choked, the emerging air over-expands and contracts periodically and sets up a series of standing shock waves at certain distances along the jet.

It is now fairly well established that any eddy moving downstream with the jet gives forth a sound wave as it passes through the shock waves, the sound in turn travelling upstream. When the sound wave reaches the edge of the jet, the varying pressure in the sound wave causes the over-expansion to fluctuate and the ensuing fluctuating flow passes downstream. A resonance mechanism is thus established and the growth of noise with increasing pressure ratio above choking takes the form of a series of fairly well defined notes interspersed with regions where no single noise is apparent. Without any resonance mechanism there is, of course, noise production each time turbulence passes a shock wave, but this does not give rise to noise laws in which the noise level can increase as V^{29} for instance.

(*c*) A further source of noise in a jet is that caused by noisy combustion in and aft of the flame tubes. Very little has been done to examine the magnitude of noise from this source but it would appear to be appreciable and is worthy of investigation by combustion experts.

Model experiments indicate that the maximum intensity of noise from an unchoked jet is in a downstream direction at an angle of about 30-40 degrees to the jet axis, this angle being less for low frequencies than for high frequencies. These observations are in keeping with Lighthill's theory and give us confidence in deducing further conclusions from the theory. From a practical point of view it also suggests the advisability of correct orientation of aircraft engaged in long test runs near areas of heavy population.

Most modern jet engines are slightly choked at take-off and are heavily over-choked in cruising flight at great heights. Under these latter conditions the predominant noise arises from shock wave eddy interference and resonance and is greatest at an angle somewhat greater than 90° to the jet axis. This, together with the increasing excess pressure at altitude, is unfortunate for the designer of the jet air liner and is undoubtedly the reason why, in spite of the falling thrust with altitude, the noise in the cabin does not diminish appreciably.

The high order in velocity mentioned, to which the noise corresponds (V to the eighth power subsonically and far higher when the jet is well choked) should give the greatest clue to noise suppression in the future. Bearing in mind that in flight it is the *relative* velocity to this power that is the essential parameter, a very good return should be obtained from any reductions in jet velocity, even when the mass flow is increased to give a constant thrust. Certainly this possibility, reducing as it will the stream to an unchoked condition, cannot be neglected and it would be useful to hear engine designers' views on the feasibility of such reductions.

NOISE SUPPRESSION DEVICES

Several noise suppression devices have been invented and tried out successfully on over-choked jets and reductions in noise levels of as much as 15-20 decibels have been achieved in model experiments. The College of Aeronautics has invented a jet pipe with fingers inserted slightly into the jet stream around its periphery. This appears to be most effective while giving rise to little or no loss in thrust. Subsonically, the device is still effective, although to a less extent, and on model jets gives rise to a reduction of some 4 or 5 decibels. Rolls-Royce have tried out the various devices on a full scale rig and the answer to "the 64 dollar question" of how do they behave on full scale engines should be received from Mr. Greatrex shortly.

Southampton has put forward a corrugated jet pipe which is possibly easier to maintain and which works very effectively at over-choked jet speeds, giving noise reductions in the model scale of some 15-20 decibels. Subsonically there is no reduction at all using this device, so that it would be useless on an unchoked jet engine.

In the over-choked case, it is thought that the mechanism of noise reduction is primarily the elimination of the resonance mechanism, which so greatly aggravates the noise, by preventing the formation of any discrete eddies. Thus, in full scale where the turbulence and swirl in the jet may be large, the reduction so obtained on the model may already have been obtained

without the fitment of the fingers, or the fluted jet exit.

Subsonically again it is thought that the reduction is obtained by a reduction of the velocity shear at the jet exit. Since any such device essentially gives rise to added turbulence, the noise reduction obtained must depend on a fine balance between that gained by shear velocity reduction and that lost by the added turbulence. Thus the increase of noise obtained with the fluted jet could result from too large an increase of turbulence.

The reduction of shear is accompanied by some increase in spread angle of the jet. Thus the device may not be suitable for aircraft in which the jet streams already pass very close to the rear fuselage or tailplane.

In conclusion, no mention has been made of the structural and helicopter aspects of jet noise but these are referred to in my paper in the May JOURNAL, already mentioned, and which may be referred to in the discussion.

Engine Noise

by

F. B. GREATREX, B.A., A.M.I.E.E., A.F.R.Ae.S.
(Rolls-Royce Ltd.)

THE TITLE OF THIS paper could cover a number of interesting problems ranging from the ultrasonic scream from compressors and its (alleged) effect in producing "jet sickness," to the noise from supersonic propellers but, since it is "in particular Jet Noise" which is under discussion, this paper deals entirely with that subject. Some new facts are presented, mostly obtained at my own firm, with the active encouragement of the Ministry of Supply, and some of their implications are discussed.

1. The Noise Field round the Jet from a Jet-engine

Figure 1 shows diagrammatically a typical set of conditions in which we are interested round the rear end of a jet engine. To complete the picture Fig. 2 shows a typical velocity and temperature traverse across the jet as it leaves the final nozzle. It will be seen that both velocity and temperature remain very uniform* to within $\frac{1}{4}$ inch of the walls.

A very complete set of noise measurements over a wide range of r.p.m. has been made round a Derwent engine mounted on a special test-bed out in the open. Some of the results are shown in Fig. 3 as noise contours round the engine running at its maximum continuous r.p.m. for seven out of the eight octave bands of a Standard Telephones Analyser (the highest frequency band was faulty at the time of the test). Very similar contours have been obtained round an Avon engine and also, round some American engines, so that the general pattern of noise appears to be independent of the type

*It will be noted that the measured figures differ slightly from those quoted in Fig. 1. This type of discrepancy will occur throughout this paper, wherever the actual values do not affect the argument, as it cannot always be avoided when tests have to be made piecemeal on different types of engine as they become available.

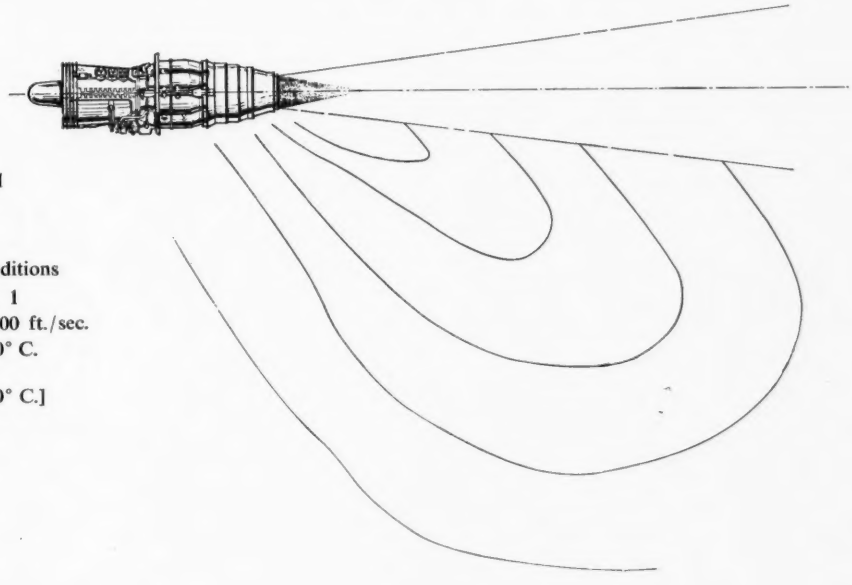


FIGURE 1. Noise field around typical jet engine.

Take-off conditions	
Jet Mach No.	1
Velocity	1,800 ft./sec.
Temperature	450° C.
[Total temperature in jet	600° C.]

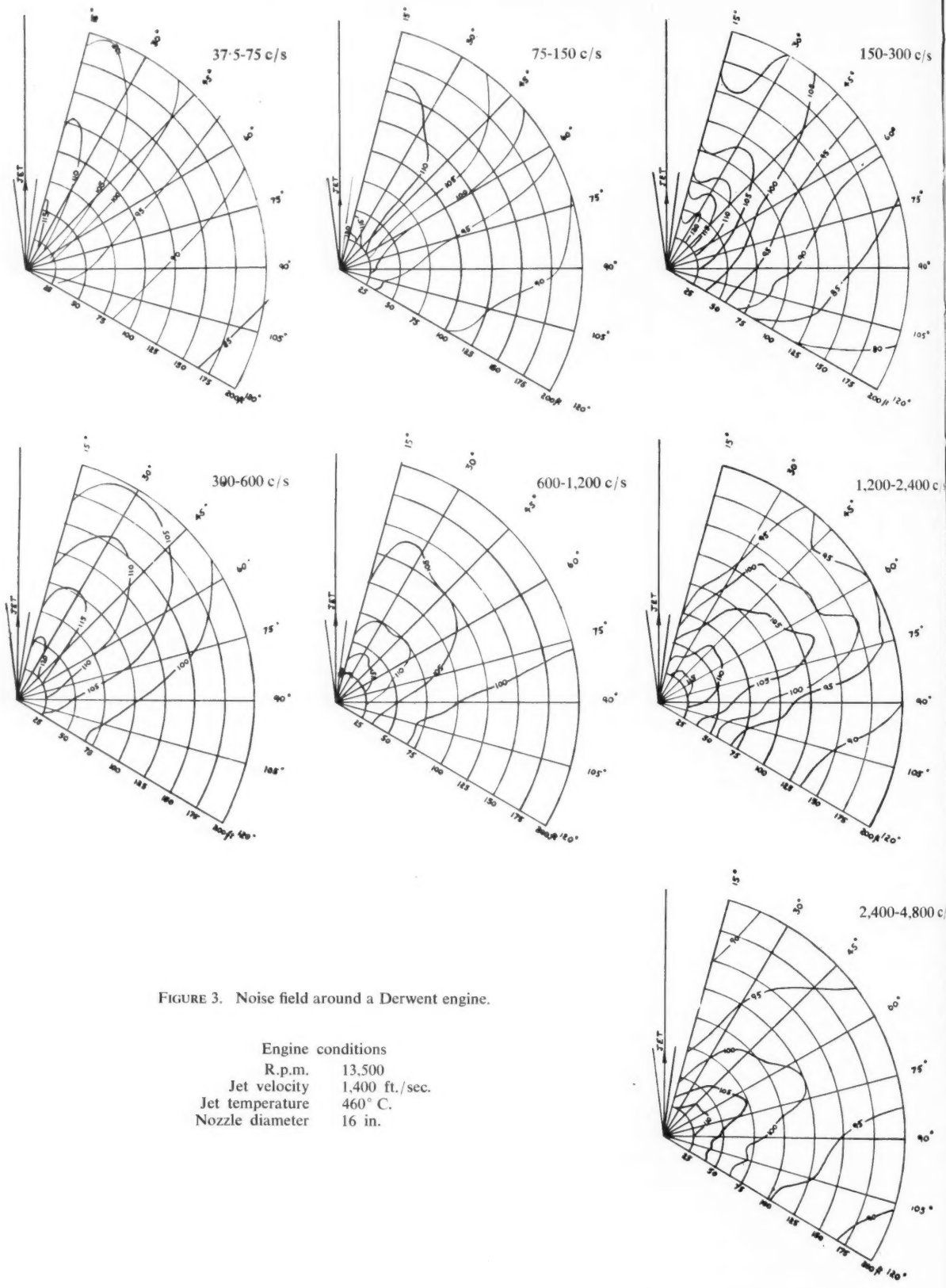


FIGURE 3. Noise field around a Derwent engine.

Engine conditions	
R.p.m.	13,500
Jet velocity	1,400 ft./sec.
Jet temperature	460° C.
Nozzle diameter	16 in.

of engine, as one would expect if it is entirely due to the interaction of the high velocity jet with the surrounding air.

2. Comparison with Model Jets and with Theory

The variation with frequency of the angle at which the peak noise occurs is generally very similar to the variation obtained on model tests, the actual figures being 14° from the jet centre line in the 37·5-75 cycle band, varying round to 70° in the 2,400-4,800 cycle band. The apparent source of the noise also seems to be farther downstream at the lower frequencies, as in the model tests.

The loudest noise appears to occur at approximately 30° to the jet axis. A point on this 30° line, at 20 yards radius from the jet nozzle, has therefore been chosen for more detailed investigation of the available results. In Fig. 4 the overall sound intensity at this point, summed over the whole frequency band, has been plotted against the jet velocity for the Derwent and Avon engines already mentioned and also, for a larger engine of 9,000 lb. thrust rating and (a single point) for a Nene engine. The results throw some interesting light on the main points of the Lighthill theory:—

(1) The theory implies that the noise produced by a jet is independent of the jet temperature, and model tests have supported this. In these full scale tests jet temperature variations over the measured range of r.p.m. of 145°C. for the Derwent, and 70°C. for the Avon, have not produced any deviation from a straightforward power law relationship between noise and velocity.

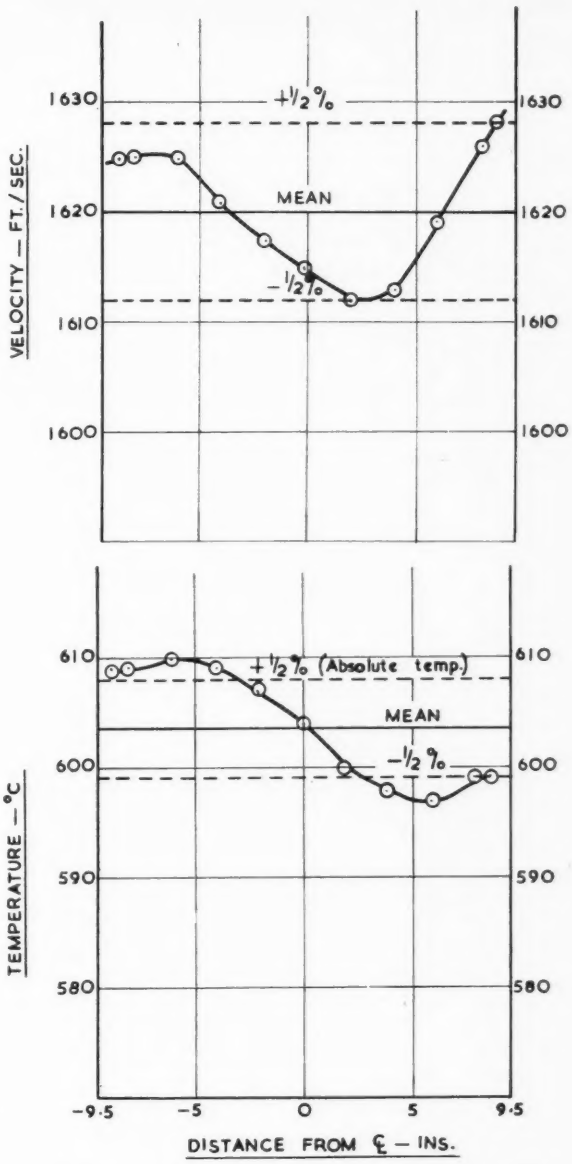
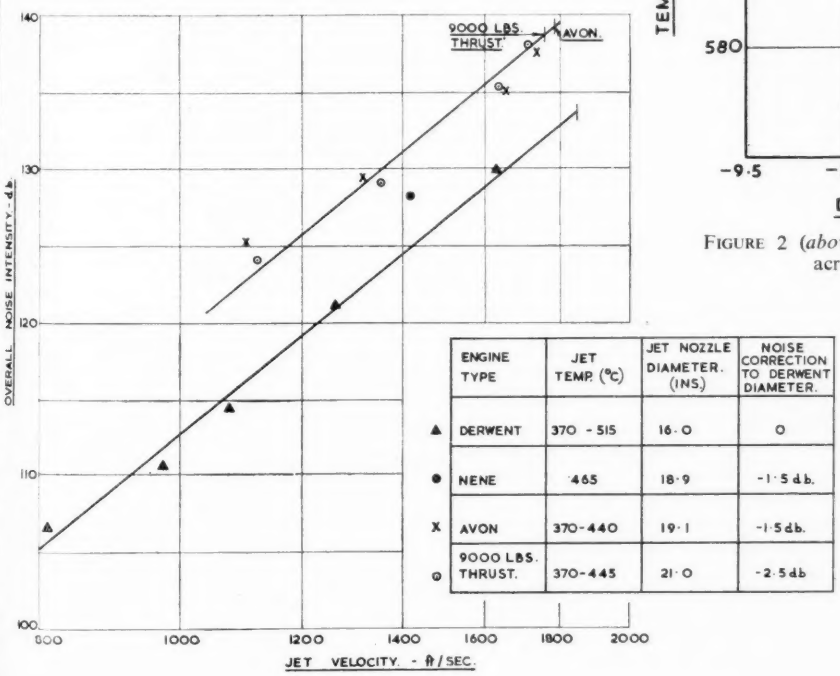


FIGURE 2 (*above*). Velocity and temperature traverses across jet nozzle of Nene engine.



	ENGINE TYPE	JET TEMP. (°C)	JET NOZZLE DIAMETER. (INS.)	NOISE CORRECTION TO DERWENT DIAMETER.
▲	DERWENT	370 - 515	16·0	0
●	NENE	465	18·9	-1·5 db.
X	AVON	370-440	19·1	-1·5 db.
⊙	9000 LBS. THRUST.	370-445	21·0	-2·5 db

FIGURE 4 (*left*). Variation of noise with jet velocity for different engines. Measured at 20 yards radius, 30° from jet axis.

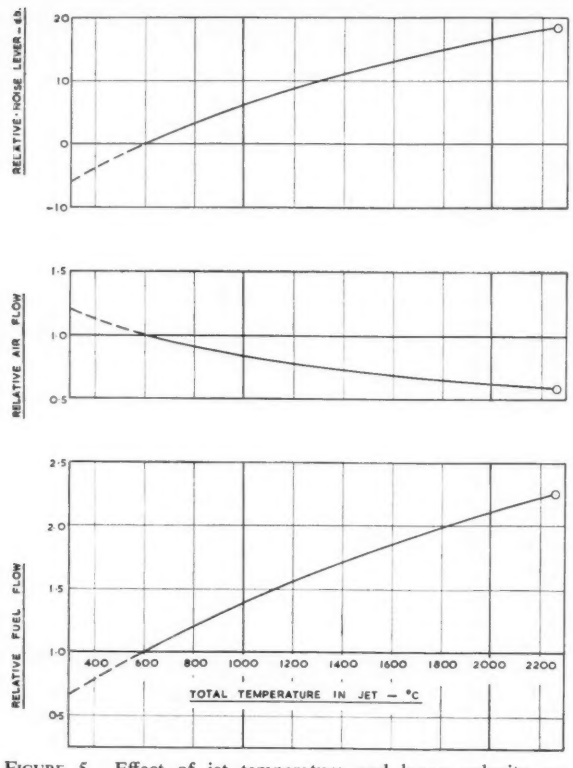


FIGURE 5. Effect of jet temperature and hence velocity on noise, air flow and fuel flow at constant thrust. Simplified curves assuming constant pressure ratio in jet.

(2) The results concerning this power law relationship are particularly striking; the index is exactly 8 for the Derwent results, agreeing precisely with the theory. For the Avon and "9,000 lb. thrust" engines, the same power law gives a very good fit with the points. This is particularly interesting as the top Avon point, and the top two "9,000 lb. thrust" engine points, are at jet pressure ratios well above the critical.

Any shock wave phenomena that may be occurring do not seem to have had any appreciable effect on the noise. It is clear that subsonic laws can be used to predict ground running noise even though the critical pressure ratio is exceeded.

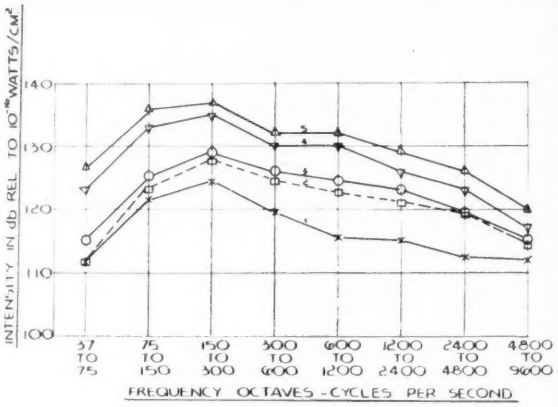
(3) The theory predicts that the noise should vary as the square of the jet nozzle diameter. The appropriate correction for this is given in the table in Fig. 4 and it will be seen that it is nothing like sufficient to account for the difference between the engines—there remains up to 7 db "error." This is disappointing but as the measurements were made under different conditions (only the Derwent measurements were made on a test-bed designed specially for noise work) and with different Noise Analysers, it is perhaps better not to draw any hard and fast conclusions on this point.

The lines through the points have been extended up to the jet velocity corresponding to the maximum take-off r.p.m. in each case, so that the maximum noise levels to be expected with each type of engine can be read off the graph.

3. Re-heat

It is clearly high jet velocity which is the real culprit in producing noise. It is therefore unfortunate that one of the most useful methods of getting a large thrust out of a small engine, by the use of re-heat or after-burning in the jet-pipe, depends entirely on increasing the jet velocity.

Figure 5 shows the principles involved. Consider a series of engines, starting with one having a total temperature in the jet of 600°C. Keeping the pressure ratio, and hence the Mach number in the jet constant, and by burning increasing amounts of fuel, the temperature, T, in the jet is raised so that the velocity, V, increases as $\sqrt{T}$, but the thrust is kept constant. It will be seen that it is an extravagant process; the amount of fuel needed to produce the given thrust increases very rapidly as shown in the lower curve. But the hotter engines are smaller, as can be seen from the reduced air flow shown in the middle curve (and this of course is the great advantage to the aircraft designer of this type of engine).



Graph	Condition	Nozzle diam. (in.)	Nozzle velocity (ft./sec.)	Thrust (lb.)	Overall intensity level (d.b.)	*Corrected intensity level (d.b.)
1	Standard engine cruising r.p.m (13,500)	16	1430	2210	128	128
2	Standard engine maximum r.p.m. (14,700) fitted	16	1680	3390	132½	127
3	Re-heat pipe fitted but no re-heat (14,700 r.p.m.)	16	1680	3390	132½	127
4	Re-heat 12·6% boost	18	1880	3940	138½	128
5	Re-heat 23·3% boost	19·5	2010	4315	141½	128

*Measured intensity levels corrected to nozzle diameter and velocity of Graph 1 according to the law intensity $\propto d^2 V^8$.

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FIGURE 6. Octave analyses of noise from Derwent V engine with and without re-heat, taken at Pyestock.

It turns out that the jet nozzle diameter remains constant for this series of engines so that the noise should increase as V^8, *i.e.* T^4 as in the top curve.

Fortunately there is a limit to this process, at the stoichometric temperature, and for this reason the curves have been plotted against temperature instead of against velocity directly. It can be seen that the maximum increase of noise to be expected on this type of engine is about 18½ db due to the increase in velocity alone.

In practice, re-heat is applied to an actual engine, increasing the nozzle area so that the air flow is maintained constant. Nozzle area and thrust then increase in proportion, by about 70 per cent. in the limiting case, producing a further contribution to the noise of 2½ db (accepting the Lighthill theory). Thus the maximum possible increase of noise due to applying re-heat to an existing engine of this type is about 21 db. This would give an overall intensity at 20 yards radius and 30° angle of 160 db on an Avon.

The effect of re-heat on noise can be expressed in another way—if an increase in thrust is obtained by re-heat the noise is increased as (thrust)^9, whereas if the same increase in thrust is obtained by building a larger engine, the noise is increased simply as the thrust.

There is another aspect of the problem which should be mentioned as it is already causing trouble on some aircraft, even without re-heat—that is that minor structural fatigue failures can occur due to vibration caused by pressure fluctuations from a jet. Obviously this trouble will be greatly intensified by the use of re-heat.

Fortunately, in so far as it concerns noise and vibration, these very large thrust increases are still unrealised in practice. Firstly, due to the obstructions required in the jet pipe to produce stable combustion, the jet velocity and hence the thrust, are less than the theoretical figure; secondly, the highest temperatures so far attained are much less than the theoretical maximum.

There is some practical evidence concerning re-heat which supplies further confirmation of the Lighthill theory. Fig. 6 is taken from a R.A.E. report on noise tests on a Derwent engine. It will be seen that the true comparison showing the direct effect of applying the greater amount of re-heat to the engine gave an increase of noise of 7½ db. On an Avon engine the corresponding increase under similar conditions has been measured to be 8 db, in very good agreement. A final column has been added to the table of figures to illustrate the close agreement with the Lighthill theory. (The contribution to the noise of the increased nozzle diameter is only 1·0 db in the first case and 1½ db in the second, so that this evidence is not of any value in assessing the correctness of the d^2 law).

It is extremely interesting to note from these tests that the increase of noise due to re-heat is no greater than the figures which have been predicted on the assumption that there would be no change in the degree of turbulence in the jet stream—for there undoubtedly *is* a considerable increase in turbulence in the main

NOISE REDUCTION DEVICES	DESCRIPTION	EFFECT ON NOISE AT HIGH R.P.M.			
		LOW FREQUENCIES		HIGH FREQUENCIES	
		15-45° FROM JET AXIS	45-120° FROM JET AXIS	15-45° FROM JET AXIS	45-120 FROM JET AXIS
	3 SQUARE TEETH, 1/12TH CIRCUMFERENCE, AT 0° TO JET AXIS 3 SIMILAR TEETH INCLINED INWARDS AT 30° TO JET AXIS.	8db REDUCTION	2-3db INCREASE	3db REDUCTION	6db INCREASE
	3 SQUARE TEETH, 1/12TH CIRCUMFERENCE, AT 0° TO JET AXIS 3 TRIANGULAR TEETH 1/12TH CIRCUMFERENCE (BASE AND HEIGHT) INCLINED INWARDS AT 30° TO JET AXIS.	6db REDUCTION	SLIGHT INCREASE	2db REDUCTION	4db INCREASE
	3 TRIANGULAR TEETH, 1/12TH CIRCUMFERENCE (BASE AND HEIGHT) AT 0° TO JET AXIS. 3 SIMILAR TEETH INCLINED INWARDS AT 30° TO JET AXIS.	5db REDUCTION	UNCHANGED	UNCHANGED	4db INCREASE
	6 SQUARE TEETH, 1/24TH CIRCUMFERENCE, AT 0° TO JET AXIS 6 SIMILAR TEETH INCLINED INWARDS AT 30° TO JET AXIS.	3db REDUCTION	2db REDUCTION	4db REDUCTION	2db REDUCTION
	8 V-NOTCHES CUT IN STANDARD CONVERGENT NOZZLE.	UNCHANGED	UNCHANGED	2db INCREASE	UNCHANGED

FIGURE 7.

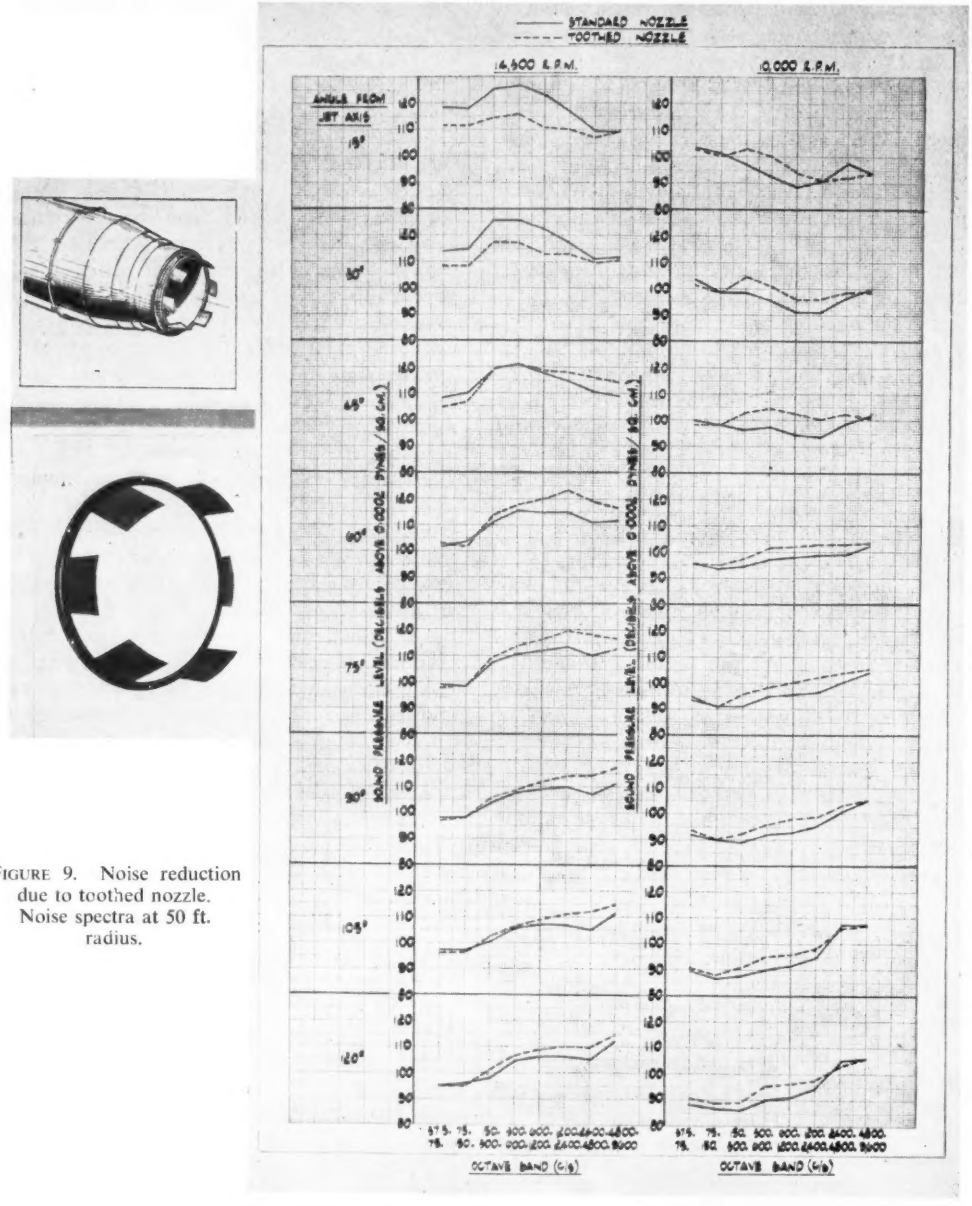

FIGURE 9. Noise reduction due to toothed nozzle. Noise spectra at 50 ft. radius.

stream, although probably not in the boundary layer in the jet-pipe. Is it perhaps only the turbulence in the boundary layer which affects the noise production?

It is clear that the use of re-heat presents a truly formidable problem in its associated noise, which must be mastered so that its performance advantages can be effectively used, at least on military aircraft.

4. Noise Reduction Methods

So much for the problems; are there any cures in sight?

There is the possibility of designing an engine from the start to use a lower jet velocity. The effect of this is roughly illustrated by the dotted parts of the curves of Fig. 5 (the simplified theory of these curves does not apply to a *reduction* in temperature, since this requires a re-design of the engine, but the general trend is correct). A practical value of temperature is 400°C. and it will be seen that the consequent reduction in noise is about 4 db.

But it must not be thought that it is only the stupidity or obstinacy of engine designers which prevents this "silent" engine from being made. The real drawback is that a low temperature engine is inevitably larger, as shown on the middle curve of Fig. 5. Since the main advantage of a jet engine is its lightness, very solid arguments are needed to support a case for a heavier engine, in spite of its reduced fuel consumption (again shown in Fig. 5, on the lower curve). Fortunately the

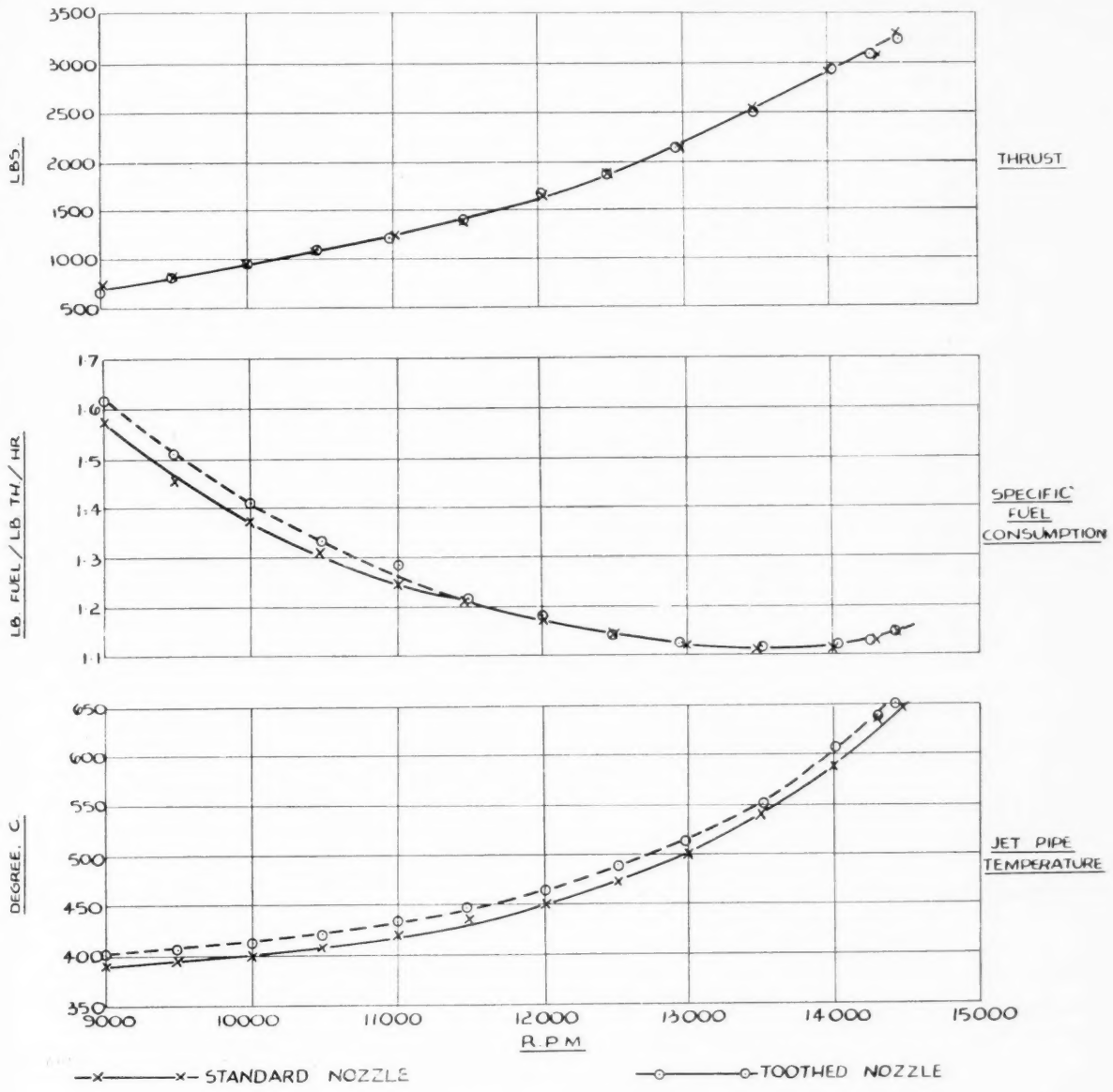

FIGURE 9. Performance of Derwent engine with standard and six-toothed nozzles.

large civil jet air liner, for which noise levels must be much less than for military aircraft, is just the right application for an engine of this type. Such an engine already exists, the Conway, and it is hoped that measurements shortly to be made will confirm the expected reduction in noise.

Secondly there are a number of additive devices which have been found to give substantial noise reductions when tested on model jets at Cranfield, Manchester and Southampton. The most promising of these, at any rate for the mainly subsonic jet speeds in which we are interested for ground running, consist of "teeth" attached to the jet nozzle, either parallel to the jet axis or bent inwards. Fig. 7 summarises briefly the results of full scale tests on a Derwent engine on some of these devices. These are not necessarily the best, but merely happen to be the first to be tested in the course of a large programme of work.

Of these the most effective is the first, 6 square teeth spaced evenly round the nozzle, 3 parallel to the jet axis, and 3 bent in at 30°. Fig. 8 shows comparative noise spectra obtained with, and without, this device at 50 ft. radius at various angles from the jet axis. It can be seen that at high r.p.m. the teeth are remarkably effective in reducing the low frequency peak noise near to the jet axis, a reduction of some 8 to 10 db being obtained, but that the high frequency peak at around 90° is actually increased.

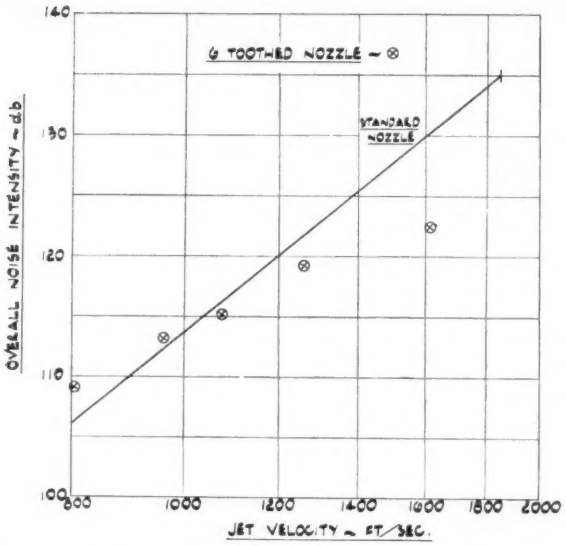

FIGURE 10. Noise reduction due to fitting six toothed nozzle.

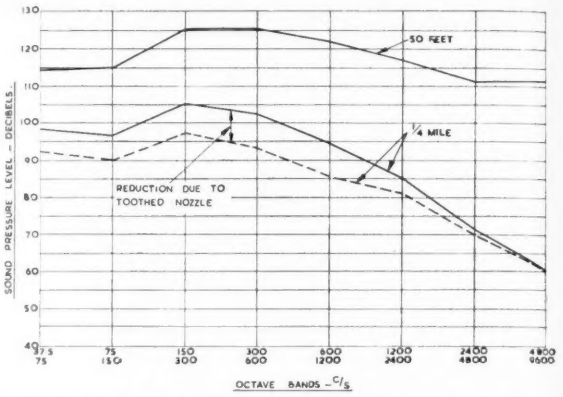

FIGURE 11. Ground running noise showing attenuation due to distance and reduction due to toothed nozzle measured on a line at 30° to jet axis.

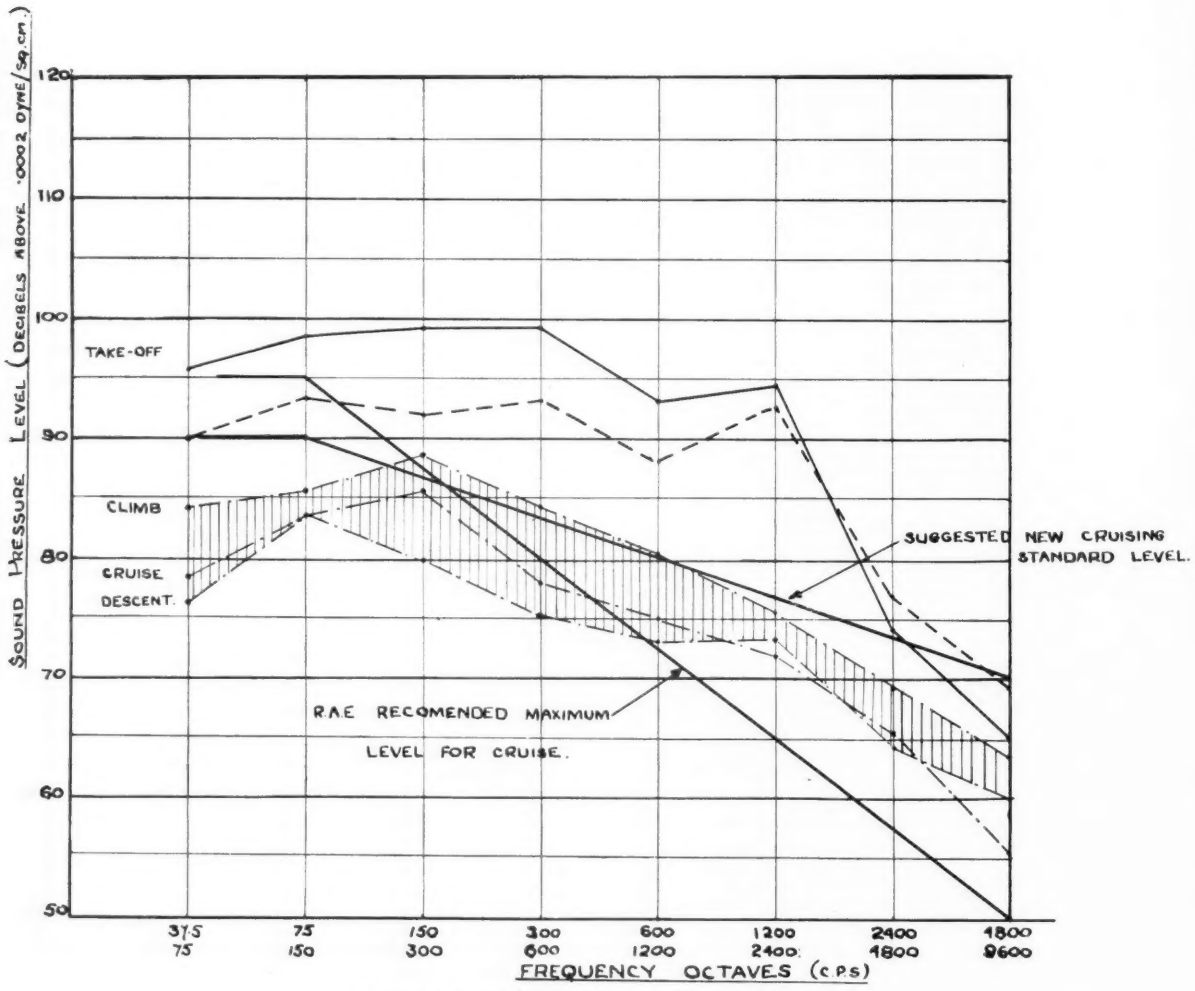

FIGURE 12. Noise level measurement on Comet.

This result seems to conflict with expectations in that it is the low frequency noise which is reduced, the noise thought to be generated by large eddies downstream of the nozzle and not affected by details of the nozzle shape. The noise reduction of 8 to 10 db is also appreciably greater than that obtained in the model tests in this subsonic speed range.

This noise reduction was obtained with negligible effect on engine performance, as illustrated in Fig. 9; the only measurable change was a very slight increase in jet-pipe temperature, thrust and fuel consumption being apparently unaffected.

The summed noise intensity at the 50 ft. radius/30° point has been plotted against jet velocity in Fig. 10, the line for the standard nozzle without teeth being taken from Fig. 4. It can be seen that the noise reduction appears to be effective only at high jet velocities. This suggests that it would not be possible to improve on the low jet velocity engine by means of this device but that it should certainly be effective with re-heat.

Summing up, it appears that a simple device is available which will markedly reduce the low frequency noise from a high (subsonic) velocity jet, although the mechanism of this reduction is not really understood, at negligible cost in engine performance and at the expense of some increase in high frequency noise. Two examples show the great practical importance of this:—

(*i*) The annoyance caused by prolonged ground running is not so much to those working in the immediate neighbourhood of the aircraft but to those living some distance away. In Fig. 11 the same Derwent noise spectrum at the 50 ft. radius/30° point is reproduced, together with an estimate of the corresponding spectrum at a distance of $\frac{1}{4}$ mile, the attenuation at the various frequencies being deduced from some experimental results obtained by Hayhurst. It is clear that the low frequency noise predominates and that a reduction to the level shown by the dotted line would be of real value. Even a slight increase at high frequencies would be relatively unimportant.

(*ii*) A similar argument applies in flight. Fig. 12 shows some average noise spectra measured in an early version of the Comet, a prototype aircraft which was not fully furnished. At take-off r.p.m. the noise is uniformly high over most of the lower frequencies; the dotted line shows the improvement obtained by the use of the toothed nozzle, on the assumption that the mean reduction obtained over the 15°, 30° and 45° positions would be obtained.

The graph also shows the old Royal Aircraft Establishment recommendation for the maximum cruising noise level in a civil aircraft. Some time ago, as a result of noise tests in a Tudor with four Nene engines, we came to the conclusion that a comfortable level of noise in the cabin was better represented by the line shown as the suggested new standard. It is interesting to note that the Comet, universally acknowledged to be a very quiet aircraft, conforms to the suggested new standard, but not to the old one. Is it not time this recommendation was revised?

The climb and descent lines on this graph are interesting in that the difference between them, shown shaded, gives the order of the noise increase due to the engines—both are at approximately the same speed and altitude but on the descent the engines are throttled back and the noise is almost entirely "aerodynamic noise." If the same noise reduction is obtained at the much higher supercritical jet pressure ratios obtained in flight (and the model tests promise even greater reductions), clearly most of the noise due to the engines would be eliminated, leaving only the aerodynamic noise.

It is pleasant to be able to end on this optimistic note, but the optimism must be slightly qualified by the warning that these noise reduction devices may have other troubles associated with them, such as the more rapid spread of the jet found from model tests, which have not yet been properly explored.

ACKNOWLEDGMENTS

I should like to thank the Chief Engineer of Rolls-Royce Ltd., and the Ministry of Supply (Chief Scientist) for permission to publish this paper and to acknowledge the assistance in preparing this paper of my colleague Mr. Dryburgh, who has also made most of the tests reported in it. I also acknowledge permission to reproduce Fig. 6, which is Crown Copyright.

Discussion

A. RADCLIFFE (National Gas Turbine Establishment): Although Professor Richards had not included it in his list, the National Gas Turbine Establishment had also done work on jet noise. Work, too, had been done on pressure fluctuations in combustion systems and a paper on pressure fluctuations in an engine was shortly to be published in "The British Journal of Applied Physics."

It was possible to calculate the noise near an engine due to pressure fluctuations in the jet pipe using theories in books by Lord Rayleigh and by P. M. Morse. This had been done for an early form of re-heated engine in which the pressure fluctuations were much more severe than were normally acceptable. The agreement between theory and measurement was good.

The pressure fluctuations in a normal fully developed jet engine due to the combustion system were such as to make little contribution to the exhaust noise, which was generated aerodynamically by the jet in the manner explained by Mr. Greatrex.

MR. W. W. DRYBURGH (Rolls-Royce Ltd.): Since Mr. Greatrex had prepared his paper some confirmation of the V^8 law had been obtained. His Company had made tests on a re-heat engine using the two positions

of the nozzle, which gave a difference of velocity for the same thrust setting. In the one case, with the nozzle open, the velocity was 1,200 ft./sec., the effective nozzle size being 423 in.^{2} With the nozzle closed the velocity was 1,450 ft./sec. and the effective nozzle area was 290 in.^{2} The noise was measured in the 30° position; the calculated difference in the noise intensity due to the change in velocity was 6·6 db., and the difference in the noise intensity due to the change in effective area was 1·6 db., so that the effective change was 5 db., which agreed fairly well with the measurements, showing good confirmation of the V^8 law.

A. STEPAN (Fairey Aviation Co. Ltd.): He was engaged in pressure tests in connection with helicopter rotors and they had more or less normal combustion chambers as used for ordinary turbines, but working only at very high combustion intensity. The conditions in the combustion chamber were somewhat different due to the fact that the turbulence there, in order to maintain the burning at that very high intensity, was very, very high, and it was found that up to pressure ratios which were not very high over the choked pressure range, the introduction of pressure reducing devices had made very little difference. The only conclusion they could draw from the work would be that the turbulence was already so high that the introduction of the noise reducing devices, such as "fingers" or "teeth," did not make so much difference in the choked condition as was indicated in previous tests.

He hoped, however, that at higher compression ratios such devices might help, and he was interested to note from the illustration shown by Mr. Greatrex that the number of "fingers" or "teeth" at the outlet of the jet engine would be small. Had tests in that direction been made on big engines?

MR. FLEMING (*Chairman*): He had made some noise measurements on the jets with which Mr. Stepan was dealing; the results differed a good deal from those for the model jets with which Professor Richards and Mr. Powell had been experimenting at Southampton. In one of Mr. Powell's papers* there was a graph showing the total noise level, in db. against the jet pressure (total head above atmospheric), on a logarithmic scale, the slope corresponding to noise intensity proportional to about the fourth power of the pressure in the subsonic region, and then becoming much steeper after the jet became choked.

Comparing with those results the noise produced by one of the pressure jets he was dealing with, having a diameter only 30 per cent greater, and also operating without combustion, he had obtained results about 15 db. higher in the subsonic region (10 lb./in.^{2}), the noise level rising less rapidly with pressure to about the same level as from Mr. Powell's jet at a pressure of about 30 lb./in.^{2} Judging from what Mr. Stepan had said, the turbulence conditions in the jet were very pertinent here; the high noise level appeared to be due to the turbulence existing in the jet, and the special kind of noise which occurred in the choked condition did not appear to be sufficiently high to come into the picture.

*A.R.C. Paper 15623, Fig. 1.

PROFESSOR A. D. BAXTER (College of Aeronautics, *Fellow*): He took up Professor Richard's point about noisy combustion. He disagreed with Mr. Radcliffe, who had rather suggested that there was not much noise due to this source. He felt that there was considerable noise generated, particularly in the case of burning continuing in the atmosphere beyond the jet pipe nozzle. Such combustion did occur in re-heat systems, ram jets and rockets, and the suppression of that after-burning could make a very big difference to the noise level. It was desirable to complete combustion before the exhaust nozzle in any case from the thermal efficiency point of view, but even if that were possible, he believed that there was still a likelihood of a fair contribution to the jet noise from combustion.

Mr. Greatrex had stated that the measured noise was rather higher than was indicated by the (jet diameter)^2 law. In experiments, should one measure the noise always at exactly the same distance from the jet, or should not distance enter into any dimensional corrections of the measured noise?

There had been no mention so far of the suppression of noise from jet engines on the test bed; this noise could be a very great inconvenience to the population in the vicinity. The construction of a silenced test bed was an extremely expensive business, and if they could reduce the noise by some simple method it would be of great benefit all round.

A SPEAKER: His impression from engine tests was that in addition to the noise developed there was a very unpleasant vibration, which had been described as "belly shaking," at very low frequencies, which he guessed to be at about 10 per second. He took care to get out of its zone after being exposed to it for a very short time, for it was possible that it would cause some injury to human beings. Had the physiological effects of it been studied, and what were the most damaging frequencies?

G. M. LILLEY (College of Aeronautics, *Assoc. Fellow*): The good agreement or otherwise between the actual results and the V^8 law was not quite so important as might be thought. The V^8 law neglected the precise motions of the sound radiators (the turbulence). When these and other factors were included it did appear unreasonable to have powers of V between 6 and 8. With regard to the noise reduction devices produced at Cranfield, the finding by Mr. Greatrex that the greatest reduction occurred at the low frequencies on the full scale engines was not very surprising because the frequency at maximum noise on the full-scale engine was lower than on the model scale. In the model jet experiments (one inch diameter), where a uniform reduction of noise was found over the spectrum from 200 cycles to 13 kc., the upper limit of measured frequency was 13 kc. At full scale, in the experiments reported by Mr.

Greatrex, the frequency coverage was the same, but 13 kc. on the model scale corresponded to less than 1 kc. full scale.

A. C. CAMPBELL-ORDE (British Overseas Airways Corporation, *Assoc. Fellow*): Professor Richards had mentioned the perhaps unfair allocation of criticism to the jet-engined type of aircraft, but any new noise gave a new talking point or reason for criticism. Did Professor Richards think that, in the case of the Comet, the cranked jet pipe of the inboard engines in series 2 and 3 would be likely to accentuate the problem, with a consequential increase of noise? B.O.A.C. had not yet operated those aircraft.

None of the speakers had referred very much to the noise emanating from the front end, the intake, of the engine; he wondered if that was because it was assumed that the compressor characteristics were the dominating source of noise. From his own observations on the Comet there was a very directional and acute noise at the front end, which most of those concerned had heard when standing in the front of the aircraft when the engines were opened up or closed down. It was very shrill indeed at rather low r.p.m.

Those concerned with Comet operations knew from experience that the least noisy portion of a flight was during the run down from high altitude, when the normal procedure was to throttle back the inboard engines. Did the results given by Mr. Greatrex represent this condition or one where all four engines were throttled?

W. J. A. SAWYER (Bristol Aeroplane Company): He spoke as a testing engineer; with regard to the combustion chamber, the point had been made that the conditions of combustion might have a very considerable effect on noise, and that certainly had been confirmed. It was also found that noise was not necessarily related to the amount of energy put in. For instance, when testing with quite a small rig, at something like 20 in. water gauge, most of the noise was due to turbulence, and it could be quite as unpleasant as when putting in high h.p.

How soon could a sound reducing device be applied under testing conditions? One wanted to do something to reduce noise fairly close to the source of the noise, and he had found it very necessary, when using a silencing device, that it should shroud the ends of the pipe which often rendered essential test observations impossible.

Quite early they had learned that there must be nothing which would act as a sounding board, as would result, for instance, if the pipe were bent soon after the source.

Noise emanation from the air intake was quite important and when Mr. Fleming had done some very careful work on their jet bed arrangements the noise level at the air intake was nearly three quarters that at the discharge.

The tests on a large jet engine were made when it was entirely enclosed—apart from flight tests, of course—and it was found that although the whole of the noise problem was dealt with very effectively by silencing there was still left a residual vibration at very low frequency which some people had found to be quite unpleasant.

MR. SAUNDERS (*Student*): It had been stated that it was velocity shear which mattered in regard to subsonic noise, presumably the velocity gradient normal to the axis. To prevent that, could "cuffs" be fitted? What was the effect on the noise in an engine fitted with "cuffs"? They were used to sucking air through to cool the engines; but did that reduce the jet noise, because it reduced the shear velocity at the boundary?

Had screens been fitted anywhere to reduce the turbulence?

At present, jet pipes were usually straight-sided cones, which could not be very good from the point of view of aerodynamics. Therefore, why not try to get a tangential flow in the jet pipe and a little more proportionality?

D. RENDELL (Royal Aircraft Establishment): The theory behind the noise reducing devices was rather obscure to him. Partly they seemed to increase turbulence, which was intended to reduce noise in the supersonic in the choked condition, and partly they were intended to reduce shear. He was not clear as to what the mechanism was expected to be in devices of that kind. There were references to methods of decreasing turbulence, and from what he had heard of the noise due to combustion, it was obviously increased turbulence which increased that noise. He believed Professor Richards had said that he had increased turbulence and had reduced noise simultaneously.

Perhaps there was a clue to that in the fact that intake noise had in some cases caused such a large part of the total noise from the engine. He had gathered that in these cases the greatest noise was not in the turbine, where it would presumably be associated with turbulence, but came from the air flowing into the intake where it would be associated with high shear.

B. EALES (Percival Aircraft Co. *Student*): He referred to the re-heat problem; could Mr. Greatrex analyse his results with respect to how much the noise level was increased by increased velocity and increased shear, how much by increased temperature and how much by increased turbulence due to combustion?

T. D. READER (de Havilland Engine Company): There seemed to be two types of noise from jet engines—a tearing noise associated with supersonic flow, and a rumbling which he believed was associated with turbulence and was possibly due to a non-uniform rate of combustion in the combustion chamber. The point had occurred to him that, if there were supersonic flow through a nozzle, then normally there would be over-expansion followed by contraction, followed by another over-expansion. He felt that possibly the tearing noise could be eliminated by introducing slower moving air around the main jet. Air at point *P* (see Fig. A) would be travelling at a speed intermediate between the jet

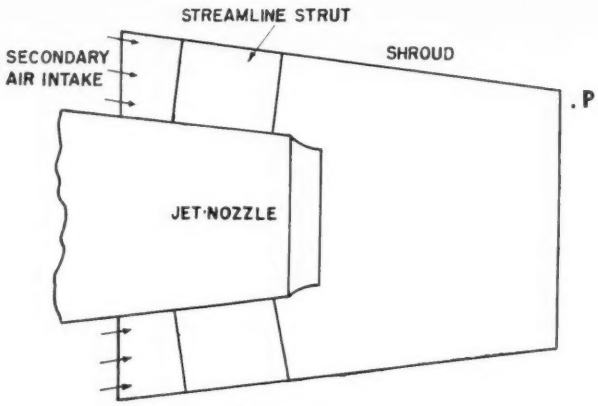

FIGURE A.

speed and the speed of the surrounding air. In that case it seemed that there would be no supersonic effect; there would be a gradual change in the velocity from the centre line of the jet outwards which it seemed would reduce the high frequency "tearing" effect usually encountered when jet velocities were supersonic.

If the rumbling noise from the combustion chamber were due to a non-uniform rate of combustion, could it be avoided by arranging a more uniform rate of injection of the fuel? Or was rumbling due to turbulence inside the jet in the region of the nozzle? Had the lecturers investigated that aspect?

N. FLEMING: It had been stated that the high frequency noise came from near the jet orifice and the low frequency noise from farther downstream. Was it the frequency at which the maximum noise occurred which came from near the jet orifice, which might be quite a low frequency in the jet engine?

PROFESSOR RICHARDS

Mr. Radcliffe had referred to the work on noise at the N.G.T.E.; although he was vaguely aware that that establishment was concerned with noise, he did not realise that they were so active in that field. He was really pleased to know about that and to know that in their experience the noise from combustion was not very great. It was interesting, however, to note that the Americans, in their tests, when they had put in quite a large amount of turbulence by providing a double bend before the pipe, so that the turbulence was on a fairly large scale, had increased the noise for a given exit speed by some 15 db. It was not known how far those results could be trusted, because they did not know the conditions of the tests, but they gave an indication that turbulence inside the engine caused an increase of noise above anything they had here. A similar conclusion could be drawn from Stepan's tests at Faireys on pressure jets. Stepan and Fleming had done a vast programme of tests on noise; in those experiments again the law was completely broken by turbulence, and again it seemed to arise from combustion noise. It might be that in the ordinary jet engine the combustion was now so smooth that they had nothing further to gain; but certainly in the case of the pressure jet they had a lot to investigate, and it was that to which he had referred.

He thought that they had come to a parting of the ways between the military and the civil engine, and he wanted to make that point very forcibly. From his "irresponsible" professorial height he did not mind getting at the engine makers and he had said that it was time they really thought about the matter. What would the future civil jet engine be like? Would it be the same as the future military jet engine, and if not, what would be the differences? Mr. Greatrex had suggested that if the air velocity were increased, the noise reducing devices seemed to work better. But that policy had never worked with aeroplanes. It was far better to eliminate the trouble at source and he felt there was a very great need to consider velocity reduction in future civil jet engines. It would be very useful to consider how much real penalty had to be paid on a long range civil aeroplane, bearing in mind that there would be reduced specific fuel consumption as well.

Mr. Greatrex had mentioned that under all conditions on the ground his engines were not sufficiently choked to make much difference; that was quite true. He had a slide which showed that for the static case the jet was slightly choked, not very much, and another showed that the noise increased as V^8; when it was choked it levelled off and then increased rapidly again. Mr. Greatrex was dealing with the part where the noise increased at V^8 and had levelled off.

In air liners at high altitudes the jets were very highly choked, and gave rise to very high noise levels which were only attenuated because of the reduced thrust at altitude and the reduced relative velocity arising from the forward speed of the aeroplane.

Referring to the noise reduction which Mr. Greatrex had effected, there could be no question that Rolls-Royce, in their full scale tests, were showing a very good practical reduction of noise. But the results did not tie up well with model experiment and there were lessons to be learnt from this. Mr. Greatrex was not getting any reduction at low r.p.m. and low jet velocities so that the mechanism could not be quite the same as in the model work. The noise reduction began to show when the speed at the edge of the jet reached about 1100 ft./sec. The mechanism was different and they did not know how far it was tied up with slight choking. The fact that the peak changed from 30° to 90° tied up with the choked jet theory, and he felt that a lot of work remained to be done along that line.

His answer to Mr. Campbell-Orde was that he should consider carefully the fitting of "fingers" to his Comet jets. There was a good chance that there would be considerable improvement from the ground point of view but, because they had turned the peak round to 90°, the noise in the cabin might possibly become a little worse. Another point was that when an aeroplane was flying overhead it was not a bad idea to have the peak at 30°, because then it was a fair distance away from the ground in the direction of the peak velocity, and they should add some 4-5 db. due to the fact that at any given height the peak was pointing more in the direction of the ground.

Dealing with the question of shear and turbulence, which seemed to have been misunderstood, what they really wanted was to reduce the shear and the velocity gradient at the edge of the jet and also to reduce the turbulence. What was happening was that when applying some of their methods of noise suppression they reduced the shear, but in the process of reducing that, put up the turbulence. That was bad and it was the reason why some of them did not work subsonically. Experiments had been made at Southampton with varying profiles and it was concluded that the best thing to do was to have a straight across profile and to try to keep the velocities as low as possible.

Low frequency noise had a peak value some distance downstream; the noise appeared to come from some distance away from the jet nozzle. The peak was not a very vicious one; there was a picture of it in his report in the May 1953 JOURNAL. As the frequency was increased, the peak seemed to move closer and closer to the jet nozzle. So that he considered that the rumbling arose from burbling downstream; there might be other burbling inside the jet.

MR. GREATREX

He did not agree at all with the remarks made about the importance of turbulence; he believed that in a jet engine the noise from the jet had very little, if any, connection with the turbulence inside the jet pipe, that the proportion contributed by the turbulence was so low that it did not matter. According to the evidence, all the turbulence that was put in with re-heat did not matter.

He agreed that when the flames actually came out of the jet pipe the noise was bound to be greater, because the degree of turbulence was then of an entirely different order. There was bound to be noise from combustion. He believed the theory of it was that the bubbles of vapour collapsed explosively. But that was inside the combustion chamber, and by the time any gas came to the jet pipe there was no turbulence left in it that mattered, so far as the ability to produce noise was concerned. He assured Mr. Campbell-Orde that a 5° bend in a jet pipe would not cause the slightest increase in the noise of the engine.

It had been said that velocity reductions were needed to produce quiet engines, and he could not agree more; but he had explained why they were difficult to achieve in practice so far.

His point about the fitting of " teeth " was of course that, if there were already a noise due to a high jet velocity, the " teeth " were very effective, but that with a reduced velocity it was possible that the " teeth " would not have much effect.

It was very disappointing that none of the speakers had taken up the problem of noise reduction and had found it of real interest. It seemed to him that something had been achieved which would be worth while in civil aircraft. The 8 db. reduction was a genuine result and he was anxious to fly it and prove its worth.

AIRCRAFT NOISE

MR. W. MAKINSON presided and opened the second session on " Aircraft Noise." A few years ago, he said, aerodynamic noise was practically a non-starter among sources of aircraft noise, but that was now far from being true. In order of intensity the sources of noise were then considered to be the propeller, the engine, mechanical noises and, lastly, aerodynamic noise. Since those days, however, air speeds had greatly increased. The modern jet engine was itself a prolific source of aerodynamic noise and there was also high speed " friction " or " boundary layer " noise due to the passage of the aircraft through the air. These sources could not now be ignored from the points of view of either the pilot, the passengers or the people on the ground.

In addition, associated with supersonic flight was the " sonic bang " which had been the subject of much publicity and controversy. Others present, like himself, would be particularly interested in the paper on this phenomenon.

Aerodynamic Noise

by

G. M. LILLEY, M.Sc., D.I.C., A.F.R.Ae.S.

(*College of Aeronautics*)

THE heading aerodynamic noise includes all cases where sound is generated by fluid flows. It includes aeolian harps, edge tones and related phenomena as well as vortex, boundary layer, wake and jet noise. In the strict sense it does not include propeller noise and the direct noise generated by bodies in motion. However, in view of their importance as sources of aircraft noise some of their more important aspects will be discussed briefly and compared with the similar properties of pure aerodynamic noise.

In general it is audible aerodynamic noise which is of major interest at present, but it would be unwise to neglect entirely the ultrasonic aspects. These have received little attention as yet.

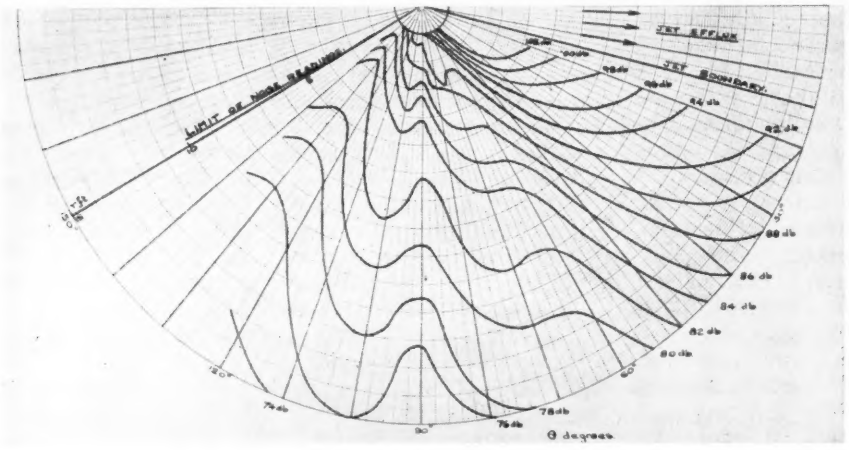

FIGURE 1. Sound field from jet below choking.

$$\frac{p_s - p_o}{p_o} = 0{\cdot}5$$

Frequency 800-1,600 c/s.

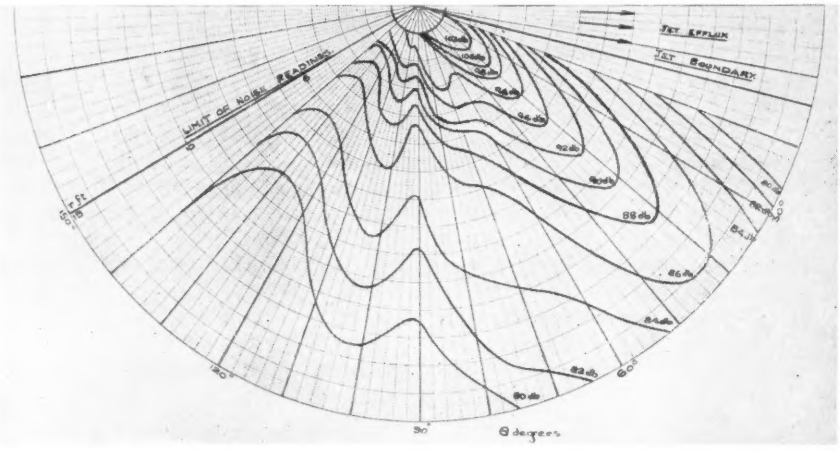

FIGURE 2. Sound field from jet below choking.

$$\frac{p_s - p_o}{p_o} = 0{\cdot}5$$

Frequency 6,400-12,800 c/s.

Classical Work

Early work in acoustics recognised the importance of aerodynamic noise as the explanation of such phenomena as bird calls, aeolian harps and edge tones. In these cases it was shown that the sound was generated by instabilities in the flow caused by vortex formations. Although these investigations led to a qualitative understanding of the frequency spectra, a dynamical theory was lacking. In addition, the importance of the conversion of a small part of the mechanical energy in the flow to acoustic energy was not studied. It is not surprising, with the recent rapid progress in the understanding of jet noise, that some of the new ideas should be applied to these classical problems[2, 12].

Propeller Noise

Although it was known[10] that aerodynamic noise (generated from the boundary layers and wakes) was responsible for a large percentage of the total noise heard in aircraft cabins and was comparable to the noise from the propeller and engine exhaust, it is only in the latter cases that extensive investigations have been made. Propeller noise is generated by periodic excitations in the flow due to the rotating blades. These are the result of (*a*) the displacement of air caused by the moving blades (torque noise) and is represented mathematically by a distribution of acoustic sources, and (*b*) the forces exerted on the air by the moving blades (thrust noise) and is represented mathematically by a distribution of acoustic dipoles[6, 3, 4]. In addition there is the noise due to the vortex motion in the wake or slipstream. Also, at high speeds the shock waves which are present increase the high frequency content of the noise.

In view of the success of the theory in reproducing the measured frequency spectra, the acoustic power, and the directivity of the noise from the rotating system, similar theories can be expected to explain the noise due to the propeller in forward motion, as well as to explain the direct noise due to bodies (*i.e.* aircraft) in motion through the air (Warren 1952). The magnitude of the acoustic conversion efficiency η is very high and near sonic tip speeds is about 0·1. ($\eta = P/W$ where P is the acoustic power output and W is mechanical energy input.)

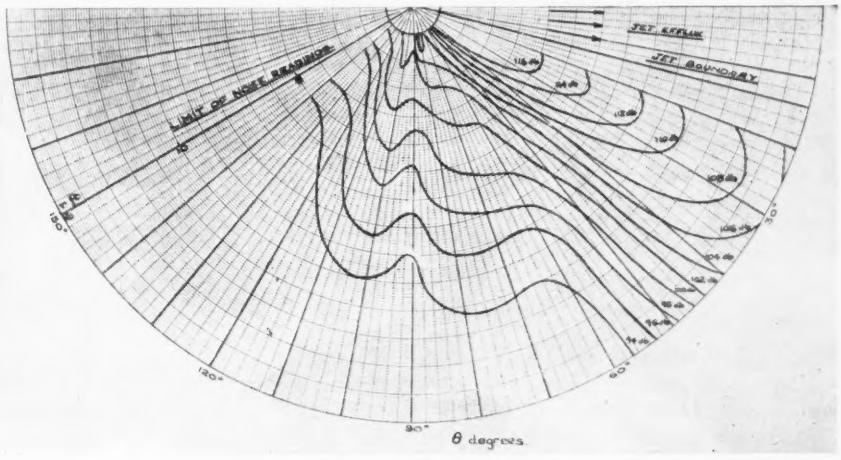

FIGURE 3. Sound field from jet above choking.

$$\frac{p_s - p_o}{p_o} = 2{\cdot}0$$

Frequency 800-1,600 c/s.

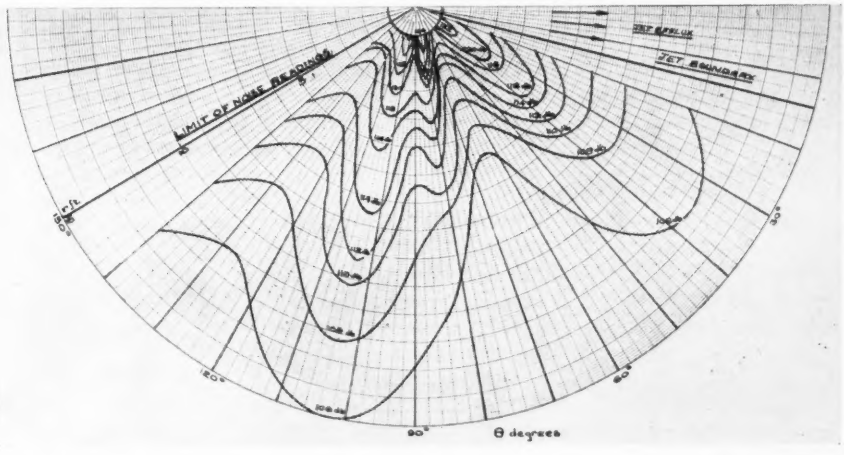

FIGURE 4. Sound field from jet above choking.

$$\frac{p_s - p_o}{p_o} = 2{\cdot}0$$

Frequency 6,400-12,800 c/s.

Lighthill's Theory of Aerodynamic Noise

Lighthill[7] has shown that the exact equations of an arbitrary motion at subsonic speeds in a compressible fluid can be expressed as the equation of sound in a uniform acoustic medium at rest, due to externally applied fluctuating stresses. The resulting equation may be written

$$\frac{\partial^2 \rho}{\partial t^2} - a_0{}^2 \nabla^2 \rho = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}, \quad . \quad . \quad (1)$$

where

ρ is the density at the point $\mathbf{x}$ at time t

a_0 is the speed of sound in the uniform medium

and the applied stress tensor T_{ij} is given by

$$T_{ij} = \rho v_i v_j - p_{ij} - a_0{}^2 \rho \delta_{ij},$$

where v_i is the velocity component in the x_i direction

$$p_{ij} = -p\delta_{ij} + \mu\left(\frac{\partial v_j}{\partial x_i} + \frac{\partial v_i}{\partial x_j} - \frac{2}{3}\frac{\partial v_k}{\partial x_k}\delta_{ij}\right)$$

δ_{ij} is the unit diagonal tensor

μ is the coefficient of viscosity,

and repeated suffixes are to be summed.

The right hand side of equation (1) represents the instantaneous strength density of a volume distribution of sources of sound in a stationary and uniform acoustic medium in which the constant speed of sound is a_0. In applications of the theory it is assumed that the turbulent region, for instance the jet field, is immersed in fluid in which the only motions are due to the acoustic disturbances propagated out from the turbulent region. Thus, outside the turbulent region the right hand side of equation (1) vanishes. In this case the retarded potential solution of equation (1) gives the fluctuations in density, which are propagated acoustically, in the region outside the turbulence. This is

$$\rho(\mathbf{x}, t) - \rho_0 = \frac{1}{4\pi a_0{}^2}\int \frac{1}{r}\frac{\partial^2}{\partial y_i \partial y_j} T_{ij}(\mathbf{y}, t^*)\, d\mathbf{y} \qquad (2)$$

where ρ_0 is the uniform density in the external region

$$t^* = t - r/a_0$$
$$r = |\mathbf{x} - \mathbf{y}|$$

and the integration is taken over the turbulent region. The retarded time t^* is used since a change in T_{ij} at $\mathbf{y}$ will not be observed at $\mathbf{x}$ until time r/a_0 later.

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gave the variation of noise with diameter at a fixed distance, or at a given number of diameters.

On the question of aerodynamic noise, what correlation was there between theory and practice? Rolls-Royce had made some measurements of noise in a Canberra at varying speeds and altitudes and had proved to their satisfaction that cabin noise was entirely aerodynamic; and at a constant indicated air speed the noise was independent of altitude.

At high altitudes the noise in the cabin of the Comet was very much less than at the take-off. Would one not expect it to be otherwise if the high frequency overchoked noise was serious?

He wondered if they were perhaps exaggerating a little when talking about flying level at supersonic speeds at a height of a few thousand feet. Furthermore, the aircraft would not usually be stressed for it. Admittedly if, according to theory, doubling the height would reduce the noise by only 3 db. altitude alone would seem to be worth little in noise reduction.

DR. E. G. RICHARDSON (King's College, Newcastle on Tyne): He felt that, inasmuch as the members of the Acoustics Group of the Physical Society had suggested the discussion, some of them ought to take part. He was afraid they were not very well represented at the symposium because, apart from Mr. Fleming and his colleagues, not many of them were working on jet noise. But they were present as seekers of information.

Discussing the relation of the Lighthill theory to the experimental polar curves of noise, he wondered whether it had been considered that, if there were turbulence in the region where a noise was produced, there would be also a scattering of the sound by the turbulent field which scattering, something like the scattering of light in a fog, might tend to even out the sound distribution. On a gusty day in the atmosphere when there was plenty of turbulence, the polar curve of a loud-speaker out-of-doors was not such as one would expect from diffraction theory. A factor like that might account for some of the differences between theory and practice mentioned in the papers.

He was not quite clear what Professor Richards meant by the reference to resonance in the jet. Was it like that produced by Hartmann using a supersonic jet coming out of an orifice? The impinging of the jet on an annular ring produced a strong and fairly pure source of high frequency sound or, if the jet were fast enough, would produce an ultrasonic vibration. Was Professor Richards considering a similar sort of mechanism?

He might be introducing a red herring, but could measurements be made on under-water jets? He believed that long before there were jet aircraft there were a few jet ships; about the year 1880 the Admiralty had built some torpedo boats for the propulsion of which under-water jets were used. The water was sucked in amidships and directed out at low speed towards the stern. That system was dropped, but now there was apparently some interest in under-water jets at higher speed, and it occurred to him that information might be obtained from the results of investigations of turbulence and noise in powered under-water jets. The speed of sound in water was 1500 metres per second, and the noise produced might be due to cavitation rather than supersonic noise, so that he was a little dubious about the possibility of making such measurements except at low speeds. At the meeting of the Acoustical Society of America, which he believed was taking place at that time, there was a paper by Mr. Nyborg on under-water jets.

A speaker had asked about low frequency vibrations in the body; some work was being done at the Queen Mary College Medical School on that subject, mainly to determine the effect of the use of pneumatic drills in the streets on the nerves of the operators. Enquiries there might yield some results.

ALAN POWELL (University of Southampton): The Lighthill prediction of V^8 assumed that the effect of the Mach number of the flow was negligible, and if they included the effect of the Mach number of the flow, the index would come to something larger than 8. On the other hand, the experiments had shown that the frequency did not vary proportionally to the velocity, an assumption which was made in the dimensional analysis. One would find on the low Mach number theory prediction an index of 5 or 6, which could be brought up to the observed number in the neighbourhood of 8 by the effect of the Mach number of the turbulence generating the noise.

Some measurement of the velocity of that turbulence had been made at Southampton, using methods which were unique. A photoelectric device was used in conjunction with a Schlieren apparatus and the outputs from two points in the field correlated, and from that one could deduce the speed of the turbulence passing downstream. As Mr. Lilley had suggested, it was found that the velocity of the turbulence increased in the downstream direction. In one particular case the eddies doubled their speed within two diameters distance of the orifice. That would have a powerful effect on the directionality of the sound. It meant in effect that the turbulence (not the velocity of the flow) downstream was moving faster than that close to the orifice, so that the peak of the low frequency sound level might be expected to be at a rather more acute angle to the jet direction.

Mention had been made of resonance effects in jets. That type of phenomenon was found at a very early stage in the work at Southampton with supersonic jets*. The essential thing was that with the supersonic jet the flow would expand and a system of nearly equally spaced shock waves would be generated. Each eddy would create a noise with the successive shock waves in the system. There were then three or four acoustic sources which would interact and give a highly directional pattern of the sound. Theoretically†‡, having

*POWELL, A. (1951). A Schlieren study of small scale air jets and some noise measurement on two-inch diameter air jets. A.R.C. 14726, December 1951.

†POWELL, A. (1952). On the noise emanating from a two-dimensional jet above the critical pressure. A.R.C. 15472, June 1952; *Aeronautical Quarterly*, February 1953.

‡POWELL, A. (1952). On the mechanism and reduction of choked jet noise. A.R.C. 15623, December 1952.

measured the velocity of the turbulence, the sound field could be predicted in close agreement with measurement. A powerful lobe occurred in the *upstream* direction close to the axis at eddy frequency, and a narrow beam roughly perpendicular to the jet axis at precisely twice the eddy frequency. The intense sound passing close to the orifice caused fluctuations of the exit angle and so generated new periodic stream disturbances.

The edge tone phenomenon*, in which they had a subsonic jet and low speed, was rather similar, with the eddies interacting with the edge, again reacting back at the orifice, and agreement of theory and experiment was shown to be quite reasonable.

On supersonic bangs, the close connection between classical acoustics and the linear perturbation theory was not always fully realised—the approximations were of just the same order.

MR. D. G. BROWN (de Havilland Aircraft Co., *Graduate*): He had examined the various theories on sonic bangs and, although he could not disagree with Mr. Warren's explanation, he would like to add his visual observations of aeroplanes performing supersonic dives. They were very difficult to see, but if one happened to know in advance that an aeroplane was going to make a dive, one could just follow its course. On each occasion he had noticed that at high altitude there was a very pronounced puff of vapour, starting with something similar in nature to a vortex, which expanded rapidly. That had made him wonder whether the sonic bang was due to something instantaneous at round about Mach No. 1, instead of being generated continuously, as had been suggested.

On one occasion when it was known that an aircraft would attempt to maintain flight at Mach No. 1, from his observation a sonic bang was not produced, but a rather long rumble ensued.

In many cases pilots of aircraft which had flown at supersonic speeds had reported that their aircraft had suffered a trim change during the pull-out, which they could only ascribe to the passage of some pressure disturbance past it. In some ways that tended to suggest that there might be something in the form of a sudden pressure change being generated at a point and transmitted downwards, and in the case of a double bang only one of those pressure changes might pass the aircraft.

Had the authors had experience of the nature of the sonic bang or noise created by American aircraft such as the Bell X—1 and Douglas Skyrocket which had achieved supersonic speeds at high altitude? Maybe, however, they were flying too high for the bang to be transmitted to the ground.

A further point in connection with the Comet, mentioned by Mr. Greatrex was that of noise at altitude; it was said that theory predicted increased noise at altitude, but that actually the noise was reduced. The Comet I operated at a jet pressure ratio of the order of 2·5, which was rather above the choking value, but it might not be high enough to be serious.

Contributed: In 1948 before the Comet prototype made its first flight an investigation was made to determine the noise levels in the cabin under flight conditions. It was appreciated that the penetration of low frequency jet noise at the rear of the cabin would be most troublesome but that some relief at high altitude could be expected.

Calculations indicated that due to altitude alone, a reduction of about 5 decibels would be expected at the cruising altitude of the Comet. Agreement with this figure was obtained later from tests in an altitude chamber on a number of small diameter air jets operating at a jet pressure ratio of 2·0 and constant jet velocity.

In addition to the altitude effect there were of course the effects of forward speed and jet velocity to consider. It was estimated that, under cruise conditions, due to the forward speed of the aircraft the sound intensity isobars would be modified in shape, giving a reduction in the cabin of about 3 decibels from sea level static conditions. However, the greatest reduction in intensity predicted arose from the effect of the change of relative jet velocity on the mixing noise due to the shear at the jet boundary. At a given r.p.m. it was estimated that this would give a reduction of about 10 decibels between sea level static and cruise conditions and a larger reduction between take-off at maximum r.p.m. and cruise.

Tests on the prototype Ghost-engined Comet (which was not fully furnished) during 1949 gave reasonable agreement with the estimates, a reduction of the peak intensity at the rear of the cabin of about 15 decibels being obtained under high altitude cruise conditions.

The position of the jet orifice was of fundamental importance and it was significant that on the Ghost-Lancastrian flying test bed the jet noise was only serious at the extreme rear of the fuselage. The noise levels in the cabin of the Comet were reduced slightly by extending the tailpipe. Under static conditions a three foot extension to the tailpipe of an inboard engine gave a reduction of 2 to 3 decibels at the rear of the cabin and a larger reduction in the rear compartment near the passenger entry door, where the noise level was normally rather high.

HANDEL DAVIES (Boscombe Down, *Fellow*): He was grateful to Mr. Warren and Mr. Yates for having removed nearly all the controversy on the sonic bang question. There seemed little doubt that it was associated with a shock wave system from the aircraft, and the so-called acoustic theory had possibly been something of a red herring.

There were one or two points which still mystified him a little; the first arose from the well-known fact that almost invariably there was a double bang and, moreover, the bangs were absolutely identical; but he was not clear as to how the shock wave system on the aircraft could possibly produce those two bangs separated by a quarter of a second.

The two main shock waves on an aircraft travelling

*POWELL, A. (1952). Edge tones and associated phenomena. A.R.C. 15333, October 1952.

at a speed slightly above the speed of sound were separated in space by a distance equal to the wing chord, and they would reach the ground separated by a time interval of less than one fiftieth of a second. The implication of what Mr. Yates had said was that there was another shock wave which was left behind. If that were so, it was new to him and he would like to hear more about it.

Referring back to the accumulation of sound energy which occurred when an aircraft approached the speed of sound, the amount of sound energy which occupied a given space directly ahead of the aircraft was multiplied by $a/(a-V)$ where a was the speed of sound and V the speed of the aircraft. This meant that the density of sound energy increased asymptotically towards infinity and, so did the frequency. This very large local concentration of sound energy must surely produce some effect.

He was not sure that people were justified in being quite so concerned as they were about the bangs which would occur from time to time, for they would be no worse than severe thunder storms, which had considerable disturbing effects on some people. The sonic bangs merely added slightly to the tribulations they had to suffer already.

MR. LILLEY

He apologised to Mr. Greatrex for having stated Lighthill's formulae in tensor notation. He felt sure that a careful study of the written paper and the relevant references would enable the basic ideas behind the theory to be understood, and at the same time the possibilities appreciated of the future predication of noise from jets or flows in which an interaction between turbulence and mean shear was present. In the written paper he had given the law for the noise intensity based on dimensional reasoning. This law gave fair agreement with the available experimental results. This law showed that the total noise intensity at a given distance from a jet was proportional to the exit area.

Mr. Greatrex and Mr. Brown had raised the problem of the noise in the cabin; the important parameter was the relative motion of the sound sources in the jet and the aircraft. He believed that was the main reason why the noise in the Comet at high altitudes was lower than near the ground. At high altitudes the aircraft speed was higher but the relative speed between the aircraft and its jet efflux was lower than near the ground.

The scattering referred to by Dr. Richardson was possibly quite a real effect, especially in the near noise field, but it had not been possible to allow for it in the experiments so far. The suggestion concerning under water experiments at low speeds was very valuable and one would like to see the results.

He agreed with Mr. Powell that too much significance should not be placed on the V^8 law. He felt that careful analysis of the available experimental results would lead to the correct interpretation of the law. He partly agreed with Mr. Powell's explanations.

It was encouraging to note that the work on high speed jets had led to new theories on edge tones.

MR. WARREN

He agreed with Mr. Yates that it was suprising that no forecast had been given of the occurrence of sonic bangs. After drawing out a lot of shock wave patterns himself, he had found that Prandtl had drawn similar diagrams in 1938; so that there was quite a lot of information on the matter.

To Mr. Handel Davies he said that when an aircraft accelerated there was unsteady flow, and a shock wave was left behind. This could be shown theoretically, and the work by Lilley had shown it experimentally. There were lots of shock waves coming off the wing, fuselage and tail, and a whole series of shock waves in fact, was left behind. As to the reason why an observer did not hear a series of bangs, it was possible that the separate shocks might be heard separately, but equally all the shock waves between tail and wing could be heard more or less together.

There were features of the sonic bang as applied to aircraft that were somewhat different from those that ballisticians had been used to, because they were not concerned with acceleration to supersonic speed in their work. In ballistics there was a strong shock wave from the explosion, a blast wave, but not from the acceleration of the projectile, which occurred in the barrel of the gun. It was the shock wave from the acceleration that was left behind in the aeroplane case.

Mr. Handel Davies had raised a point on the time interval between the bangs; in the case of rockets fired at Larkhill, where very much higher supersonic speeds were attained than with aeroplanes, the bangs from the two sources were not just a quarter of a second apart, but had arrived as much as two seconds apart. The time interval between the bangs was entirely a function of the period during which the aircraft had been flying at supersonic speeds. On the question as to whether the sound energy contributed to the bang, he agreed that the sound energy had a tremendous build-up: it was increased in magnitude by a factor of the order of one thousand. Even so, that was not enough to account for the pressures that were measured and which were, by acoustics standards, very large indeed. A tremendous build-up in intensity was required to explain it this way.

He had seen only once the puff of vapour that was left behind, to which Mr. Brown had referred, and he did not know the explanation. It persisted for some length of time in the sky just as contrails persisted, and he presumed it was associated with the occurrence of the sonic bangs. At the same time, it did not alter the fact that the sonic bang was a continuously created phenomenon. The rumble that was experienced by maintained flight at Mach number 1 might be due to the fact that it was difficult to fly at a true Mach number of precisely 1. As to American experience, at Farnborough in 1952, when sonic bangs were receiving much publicity, he and his colleagues had asked American officers whether they had experienced similar phenomena. They said that they had, but, of course, it was not nearly such a nuisance as in this country, for they operated their supersonic aircraft mainly over sparsely populated areas

and they had not put so much thought as we had into trying to explain matters.

Mr. Greatrex had suggested that flying low down at supersonic speeds, although it would cause supersonic bangs of appreciable intensity, was not very likely to occur because of the poor economy of flying low with jet aircraft. He agreed with that in the case of civil aircraft, but the military application of flying low and fast must not be overlooked, and possibly there was a role in which it would be desirable to fly at supersonic speed low down, and that could cause bangs of appreciable intensity.

Mr. Handel Davies had said that they had already to face the inconvenience of thunder storms; the cause of thunder was lightning, an electrical discharge from a cloud to the ground, and thunder could be considered analogous to the sonic bang. All that was required to cause a sonic bang was a pressure disturbance moving at supersonic speed. An aircraft was a disturbance that could move at supersonic speed: equally the heating effect of the lightning created a pressure disturbance, and thunder was thus equivalent to the sonic bang from a disturbance moving at a Mach number of, almost, infinity.

GROUND NOISE

The third session, dealing with ground noise, was presided over by DR. G. E. BELL. Introducing the authors of the two papers to be presented, the Chairman said that those who had followed the development of acoustics would know that Mr. N. Fleming, whose paper was on "Air-to-Ground Noise," had been engaged on that kind of work for many years.

The second paper, on "Ground-to-Ground Noise," was by Mr. J. D. Hayhurst, who had been engaged in various duties for the Ministry of Aircraft Production during the 1939-45 War, and later at the Ministry of Civil Aviation he had done a lot of scientific work, some of which was dealt with in the paper.

Measurement of Noise on the Ground from Aircraft in Flight

by

N. FLEMING, M.A.

(*The National Physical Laboratory, Teddington*)

1. Introduction

IN CASES of noise nuisance, measurement of the noise has several uses. It helps in deciding the degree of noise reduction which is desirable; it may serve to identify the most important source or sources of the noise where this is in doubt; and it is of assistance in devising methods for reduction of the noise. For the first purpose a single figure to characterise the noise would be preferable, but for the others some form of noise analysis is needed.

To the sufferer from the noise the most important characteristic is the annoyance it causes, or its nuisance value. This may be assessed very differently by different individuals, and consequently it is not very amenable to measurement. Nuisance depends to a large extent on loudness, which has received much more study, but so far no adequately satisfactory instrument has been devised for its measurement. In the work described in this paper the "sound level"[1] has been adopted as a single figure to characterise the noise. This is a weighted value of the sound pressure level, in which the low frequencies are reduced, somewhat in accordance with the lower sensitivity of the ear to these frequencies. It must not be assumed, however, that this is a measure of the loudness. Noises of equal sound level can differ considerably in loudness[2].

No single figure can convey much information about a noise, and the fuller description provided by an analysis is often needed. From an analysis, moreover, the sound level may be calculated and, indeed, some estimate may be made of the loudness[3, 4, 5].

For noise received on the ground from an aircraft in flight the problem of measurement is complicated by the variable and fleeting nature of the noise and, if anything more than the maximum level reached is to be measured, some form of automatic recording is needed. The present paper describes some techniques which have been tried for this purpose, and presents examples of the noise from a number of aircraft.

2. Measurements of Sound Level

The specification for the measurement of sound level defines three different frequency-response curves, corresponding roughly to the relative sensitivity of the ear to pure tones at loudness levels of 40 phons, 70 phons and 100 phons respectively. With an aircraft passing overhead at low altitude the sound level may vary from less than 50 db to more than 100 db in the course of a few seconds. For comparative purposes it would be undesirable to change the frequency-response curve of the instrument suddenly during the course of a continuous record, and for the measurements described the 70 phon frequency weighting was adopted.

The equipment used comprised a microphone and amplifier, with the overall frequency-response curve

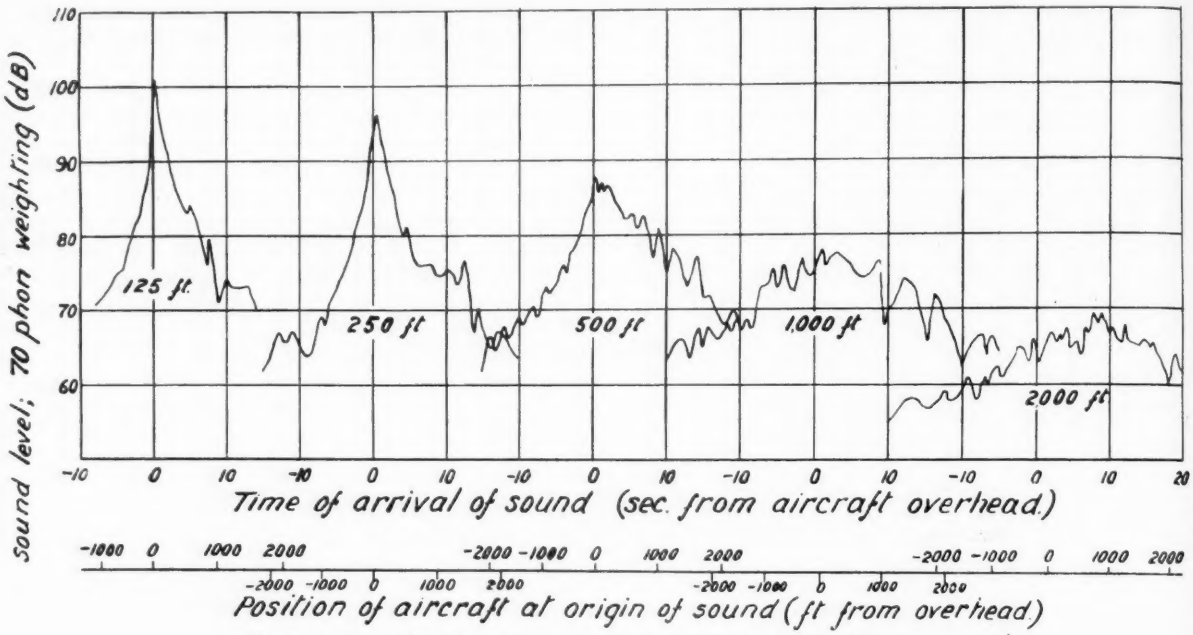

FIGURE 1. Sound level from helicopter passing overhead at various altitudes.

appropriately adjusted,* the output being connected to a level recorder. This latter instrument measures approximately the r.m.s. value of the signal applied, and records directly on a decibel scale, which in the instrument used had a total range of 50 db. A marking device was fitted and operated by an observer watching the aircraft, to mark the instant at which the aircraft passed over the microphone.

Figure 1 shows a series of results of such measurements on a single-engined helicopter. The curves are redrawn from the records, with the smaller and more rapid fluctuations smoothed out. The time scale of the record gives directly the time at which the sound reached the observation point, and the second scale, giving the position of the aircraft at the time the sound originated, is derived from this, together with the speed of the aircraft and the speed of sound. The maximum sound level in this case arises from sound originating shortly after the aircraft has passed overhead and directed rearwards at an angle of about 20° to the vertical. The distribution of the sound is markedly directional and the records afford an indication of the variation with direction in the vertical plane through the line of flight. On this occasion four runs of the aircraft were made at each height. Making allowance for the variation of the distance of the aircraft from the observation point, the records yield, on the average, an estimate of the relative sound levels for sound emitted 60° forward of the vertical, 30° forward, 0° (vertically downwards), 20° aft (the maximum) and 60° aft, of −10, −7, −2, 0 and −3 db respectively. The mean of the maximum values of the sound level for this aircraft at a number of altitudes are included in Table 1.

*At the 70 phon weighting the sensitivity relative to that at 1,000 c/s, is reduced by 15, 10, 5, 2 and 1 db at the frequencies 30, 50, 100, 200 and 500 c/s respectively.

3. Analyses of the Noise

Two methods have been tried for the analysis of the noise. The first made use of a Siemens Audio-frequency Spectrometer, which analyses the noise into 27 bands each 1/3 octave wide, and displays the results as a series of vertical lines on a cathode ray screen, which is photographed with a Kine-camera. The complete analysis is repeated twenty times per second.

TABLE I

MAXIMUM SOUND LEVEL AND LOUDNESS LEVEL ON GROUND FROM AIRCRAFT IN LEVEL FLIGHT OVERHEAD (CRUISING CONDITIONS)

Aircraft	*Sound level (db) and (in brackets) loudness level (phons) at altitude*					
	100 ft.	200 ft.	500 ft.	1,000 ft.	2,000 ft	5,000 ft.
Lancastrian 4 Merlins; tail pipes below wings	115 (126)	108 (118)	100 (104)	96 (97)	84 (86)	77 (80)
York 4 Merlins; cross-over exhaust system	107 (114)	— —	96 (99)	— —	85 (90)	
Meteor 2 Derwents	110 (122)	107 (117)	97 (104)	92 (95)	80 (86)	70 (75)
Helicopter 1 Leonides	98	94	85	78	72	—
Comet 4 Ghosts						
Take-off		110 (117)				
Landing		94 (101)				

A number of disadvantages were found in using this method.

1. The range between the smallest deflection measurable and the maximum deflection permissible without over-loading is only about 25 db. In practice the sensitivity of the equipment cannot always be successfully preset so that the instrument is just fully loaded by the highest lines, and the range is consequently reduced. In some cases, where the highest lines were always towards the low frequency end of the spectrum, the effective range was increased by making a second test with a bass cut and higher sensitivity.
2. The switch contacts the output of each filter for a period of less than 1/500 sec. Consequently the rapid random fluctuations, which are normally encountered in noise, result in considerable variations between successive frames of the film record (taken at 1/8 sec. intervals), which are not easily smoothed out.
3. The work involved in measuring the film records and in their subsequent study is excessive.

Some results obtained by this method are included in Table I (Nos. 1 to 3) where both the sound level and the loudness level have been estimated from the analyses.* In general the loudness level falls more rapidly with increasing altitude than the sound level, as a result of a more rapid decrease of the high frequency content of the noise compared with the low frequencies. Nos. 1 and 2 compare, in effect, two different exhaust systems, although the aircraft and the propellers also differed (4 blade propellers for No. 1 and 3 blade for No. 2). No. 1 had tail pipes from each bank of cylinders discharging underneath the wings. No. 2 had a cross-over exhaust system with a common discharge (above the wings) from both banks. The spectrum of the noise from No. 1 showed large peaks corresponding to the fundamental of the propeller noise at about 65 c/s and the firing frequency from one bank of cylinders at about 120 c/s. At cruising conditions the latter was the larger. With No. 2 the peak corresponding to the propeller noise (now at about 50 c/s) was of the same order as before, but the peak at 120 c/s had fallen by some 10 to 15 db. A peak at twice this frequency, not specially evident with No. 1, was now pronounced, but the level here was only of the same order as for No. 1. The general level at high frequencies was also less by some 10 db. This reduction of exhaust noise is due in part to the different type of exhaust system and, in part, to the different location of the exhaust orifices, which for No. 2 machine were shielded from the ground by the wings. The difference between the two aircraft was most marked in flights at low altitude directly overhead.

In the second method of analysis, three sets of equipment were used simultaneously, each making a continuous record on a level recorder of the sound pressure level in a frequency band one octave wide. The six octave bands with mid-frequencies from 106 to 3,400 c/s could thus be covered by two runs of the aircraft. This method proved to be much more convenient.

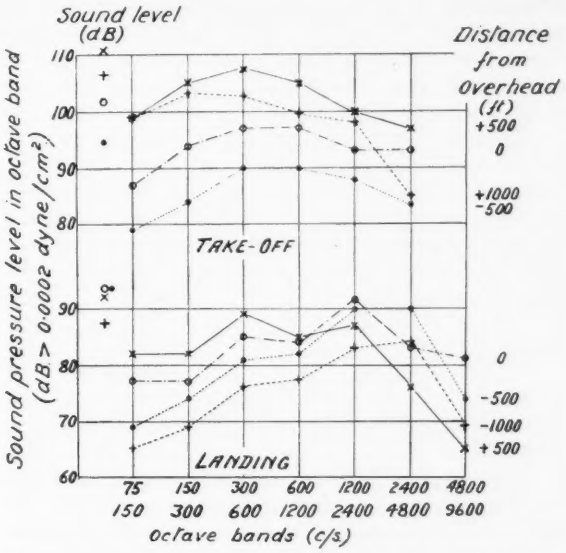

FIGURE 2. Analyses of noise from jet-engined aircraft passing overhead at altitude about 250 ft., one mile after take-off and one mile before landing.

Figure 2, which refers to a Comet aircraft with Ghost engines, shows octave analyses derived from such records. The measurements were made for normal take-off and landing conditions, at one mile from the take-off and landing points respectively. The altitude of the aircraft when passing overhead was about 250 ft. The analyses refer to the sound originating when the aircraft was at the positions stated with respect to the observation point, negative values indicating that the aircraft was approaching and positive that it had passed over. The changing character of the noise is evident from the analyses. At take-off the impeller noise (frequency 2,400 c/s) is not particularly in evidence during the approach. The low frequency noise from the jet increases very considerably as the aircraft passes overhead, and the maximum noise originates when the aircraft is about 500 ft. beyond. In landing, at lower engine speed, the impeller noise (2,000 c/s) is the predominant feature as the aircraft approaches. Owing to the Doppler effect the frequency received varies from about 2,500 c/s with the aircraft at a large distance and approaching, to about 1,650 c/s with the aircraft at a large distance and receding, and this shift is evident in the analyses. After the aircraft has passed, the impeller noise decreases, and the low frequency noise predominates, reaching a maximum at a distance of about 500 ft. beyond the overhead position. The maximum sound levels and loudness levels derived from these analyses are included in Table I.

ACKNOWLEDGMENTS

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*Estimates of the loudness level are based on Ref. 3.

Ministry of Supply. The author acknowledges the approval of the Ministry of Supply and the permission of the Director of the National Physical Laboratory to publish this paper. He also acknowledges the assistance rendered by W. C. Copeland, who helped with the observations.

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Ground-to-Ground Noise

by

J. D. HAYHURST, B.Sc., A.F.R.Ae.S.

(*Ministry of Supply*)

THE PROBLEMS of noise on the ground coming from aircraft on the ground, while still not simple to resolve, are rather less difficult than those associated with noise coming from aircraft in flight. The source of noise—the aeroplane—is no longer travelling rapidly through the air with three degrees of freedom but is either stationary on the ground or taxying at a comparatively slow speed across an airport. In the first case, the aeroplane is at rest, either for a short period when the pre-take-off check is being performed near the end of the runway, or for a much longer time while a post-servicing engine check is being made in a maintenance area. During each check, up to maximum engine power may be used, although for jet aircraft the pre-take-off check is relatively short and appears to be becoming part of the take-off itself. In the maintenance area prolonged running is likely and will consist of operation at a medium engine power with occasional bursts of maximum power. Of the three ground cases, this is the one on which attention has to be focused. Indeed, it is not unreasonable to confine an examination of the problems of ground-to-ground noise to this and to this alone.

The problem, then, is of dealing with the noise of an aeroplane in a fixed position, at which the engines may be run continuously for an hour or more. The aeroplane is available for some noise abatement treatment, subject to the requirements of the ground engineers who have to work on it, to the requirements that the engine performance must not be so altered that correct functioning cannot be checked, to the requirements of the operational staff who have to have the aeroplane ready to receive passengers soon afterwards, and to the accommodation available in the maintenance area. These requirements are not petty conditions put forward to obstruct noise abatement; they are real limitations contingent on the operation of regular and economic airline services.

When the engines are run, the noise radiated will vary around the aeroplane and will be dependent on the engine operating conditions. On an aeroplane with turbine engines, the noise will come both from the intakes and from the jet nozzles. The jet noise will be predominantly low frequency, causing the familiar roar, and will increase with increasing engine speed. With an engine with a centrifugal impeller, the intake noise will be predominantly high frequency and greatest at medium engine speeds, decaying thereafter as the engine speed is increased. At the maximum engine speed, the combined effect will be a low frequency noise with the greatest intensity in the directions rearwards, making about 45° with the length of the aeroplane. At medium engine speeds the combined effect is a high frequency noise greatest directly ahead of the aeroplane. An engine with an axial compressor gives a similar pattern at maximum engine speed, but there is much less high frequency noise at lower engine speeds; the direction of maximum noise is still at 45° to the rear. Dead astern lies an area of comparative quiet. This quiet area is found, too, in the same position behind piston-engined aircraft, on which noise comes from the propellers and the engine exhausts. The greatest noise is again experienced 45° from the rear. The high frequency noise, however, is much below the low frequency.

The aeroplane, then, is a source of noise with these general characteristics. Left to itself, the noise will spread over the ground, becoming less as the distance away from the aeroplane gets larger. Before coming to possible forms of treatment for noise abatement, it is pertinent to examine just how the noise falls off.

First, the term "noise" has to be discarded as a physical characteristic. Noise is a subjective feature that cannot be precisely defined. A proper analysis must refer instead to sounds formed of an aggregation of tones of different frequencies. Grouping the frequencies into consecutive bands, usually octaves, and taking in each octave the sound intensity (or pressure) level per octave in decibels above the conventional datum, enables an objective pattern to be established. Combining the intensity levels in decibels into a loudness level in phons, leads to a subjective presentation which can be appreciated. By doing this, account can be taken of the greater sensitivity of the human ear to the higher frequencies. Loudness levels are such that

a sound 9 phons above another will appear to be about twice as loud.

Suppose, then, at a distance of 100 ft. from an acoustic source the sound intensity in each of eight consecutive octaves is 100 decibels, *i.e.* the spectrum is flat. This emission is known, somewhat colloquially, as "white" noise. The total intensity will be 109 decibels and the loudness level 125 phons. At 200 ft. the total intensity will have fallen to 103 decibels by application of the inverse square law of energy distribution, which for sound gives a 6 decibels drop each time the distance from the source is doubled. At 400 ft. the total intensity will have fallen to 97 decibels and at 1,000 ft. to 89 decibels, made up of 80 decibels in each octave. The corresponding loudness level will be 101 phons, so that in 900 ft. there has been a drop of 20 decibels in total intensity and 24 phons in loudness level.

To these decays can be added the effects of the atmosphere through which the sound is travelling, assuming first that there is no absorption by the terrain nor any absorption, reflection, or screening from objects standing high on the terrain. It is a feature of the transmission of sound that the higher the frequency the larger the effect of any imposed condition. The atmosphere affects the transmission of sound by absorption, by dissipation caused by turbulence, by refraction caused by wind, temperature, and density gradients, and by the translational effects of wind. There are also other effects which can hardly be forecast, ranging from reflection at a layer of low cloud to reflection in the stratosphere, to which has been attributed the cause of phenomena whereby sounds have been heard hundreds of miles away from their source. Over the short distances now being considered, such phenomena can be ignored. But even with the other effects, the parameters are often difficult to define and it is convenient to group the several effects. Thus the wind effect can be isolated, so can temperature and humidity effects which, actually, are small in comparison at all but the highest frequencies. The rest can then be considered as being caused by atmospheric absorption, even though they extend beyond what is normally meant by this term. From work done in this country it is possible to forecast this combined effect with some degree of confidence. These various atmospheric effects give an attenuation which is taken, in some cases for want of better evidence, to depend directly on the distance from the source. The atmospheric attenuation increases from about one decibel per 1,000 ft. for the 37·5-75 cps. octave, to about 30 decibels per 1,000 ft. for the 4,800-9,600 cps. octave. Taking this atmospheric absorption into account, the spectrum at 1,000 ft. from the source of "white" noise will no longer be flat but will fall away at the higher frequencies. The total intensity will be about 83 decibels and the loudness level 88 phons. The narrowing of the numerical gap between total intensity and loudness level is caused by the greater reduction of the intensities in the higher octaves. It will be seen that the reduction of total intensity has been 26 decibels, while the reduction of loudness level has been 37 phons. Total intensity is a poor indicator of subjective response to sound, as is shown by these numerical differences.

The next effect to be considered is that of the wind. It is common experience that sounds travel farther down wind than up wind, but measurements have shown that the effect is quantitatively rather greater than might have been expected. The effect appears to be dependent on the first power of the wind component in the direction being investigated; that is, as though the sound drifts with the wind. In a wind of 10 knots, the attenuations will be about 4 decibels per 1,000 ft. in the 37·5-75 cps. octave and about 18 decibels per 1,000 ft. in the 4,800-9,600 cps. octave. Down wind the intensities 1,000 ft. from the source of "white" noise now become slightly greater at low frequency, and slightly less at high frequency than those found when atmospheric absorption was ignored. The corresponding loudness level is 100 phons so that the wind has just about cancelled out the attenuation caused by atmospheric absorption. Up wind the intensities are all less than those when taking atmospheric absorption into account, the loudness level being 80 phons. Thus, in a 10 knot wind the loudness levels 1,000 ft. up wind are less than those 1,000 ft. down wind by 20 phons. This is a most noticeable difference and it is important to realise that the 10 knot wind which produces it is regarded as a very light breeze.

The final effects to be considered are those caused by the terrain over which the sound is travelling. Until now the figures have been related to level concrete which will have no measurable absorption. Terrain can range from such an ideal homogeneous surface to rolling ground carrying trees and buildings, which cannot be nicely specified. These changing terrains produce effects which cannot be accurately stated; all that can be said is that they increase the attenuation. Few consistent data are available, even for grass; for trees, results have been obtained which are not very conclusive but which suggest that the attenuation in woodland is little more than over grass land.

Turning now to the question of reducing the noise in particular areas, several different methods exist which might be employed to give some abatement. It will be assumed for present purposes that all the permanent reduction that can be obtained on the aeroplane itself will have been obtained. These available methods include the application to the aeroplane of ground appliances, the use of obstacles to screen the noise, and the orientation of the aeroplane so that the highest noise levels occur in the areas where noise is of least importance. The methods can best be examined one by one. It must, however, be clearly understood that the commentary which follows reflects the author's own opinions and does not necessarily represent the views of any Government Department.

The fitting of ground silencers to piston-engined aircraft can be quickly dismissed. Equally effective treatment of the propellers and exhausts would be necessary since the contribution from each is of the same order. To silence the propellers would entail their removal and their replacement by some power-absorbing device. Not only would this take an unacceptably long time but it would also prejudice the checking of the proper functioning of the engines.

Furthermore, silencing the exhausts would also be difficult because of the many attachments that would be required. Jet aircraft offer greater scope since the sources of noise are more compact. Investigations are going on to find whether mobile detuners for the exhausts and intakes are practicable; the attendant difficulties are concerned with the design of relatively light detuners capable of withstanding jet efflux temperatures and velocities and with the design of air intake silencers which will not adversely affect the supply of air to the engines. This type of ground appliance has already been used in the United States, but there it has been limited to single types of aircraft and the arrangements have not been really suitable for everyday use in a busy maintenance area. In one case there the arrangement was little short of an *ad hoc* test house.

The use of obstacles offers wide scope but there is the limitation that the obstacles screen only a certain sector around an aeroplane. The greatest advantage will be obtained by having the aeroplane as close to the obstacle as possible, but it is clearly impossible to surrround completely the aeroplane because of the need to disperse the slipstream, or more important, the jet efflux. Another limitation is imposed by the requirement for sometimes having the aeroplane facing into wind and so it is desirable that the obstacle should be able to withstand the efflux of a jet aircraft. The obstacle can take a number of forms. Use can be made of hangars but the benefits are only small, the maximum reduction being about 5 phons, and this does not deserve any particular effort.

A better form of obstacle is provided by a running-up pen. It has been shown that reductions of up to 25 phons can be obtained this way, a reduction which represents a real measure of noise abatement. A report has already been made of a full scale investigation at London Airport using an experimental wall of asbestos sheeting fixed to a steel scaffolding. As a result of this investigation, the Ministry of Civil Aviation has built a prototype running-up pen of more permanent construction. In plan, this is in the shape of a truncated V, not because this shape has any special acoustic merit but because it enables modern aircraft to be accommodated, both nose foremost and tail foremost, with the least total length. Of course there are attendant problems still to be explored. The manoeuvring of aircraft into and out of the pen and the effect on the air flow into the intakes of jet engines may present serious difficulties. But the advantage of a running-up pen being equally effective for all types of aircraft warrants the exploration of these operating problems.

Trees have also been considered as a means of screening noise. They will certainly help, provided that they can be planted in the right place and to the necessary thickness, and that they do not infringe the safety clearances required about the approach and departure lanes for aircraft. At many airports these conditions may not be possible of fulfilment, and a few trees which may improve the scenery cannot be expected to lead to any noise abatement.

The variation of noise level around an aeroplane has already been mentioned. By so orientating the aeroplane that the directions along which the greatest noise levels are found fall on those areas where noise is of least importance, and those along which the least noise levels are found fall on the areas where noise may be disturbing, a measure of alleviation will have been achieved. But local conditions will dictate how much can be done; at many airports little will be possible. At the same time, the method may be limited by having to point the aeroplane in some direction so that it is facing into wind, or so that the jet efflux is directed away from particular parts of the maintenance area.

These are the methods available for abating the noise from aircraft on the ground. They have their limitations but admit some possibility of alleviating noise.

Discussion

THE CHAIRMAN (DR. G. E. BELL): They had heard that the noise level in a busy street was of the order of 80 db.; that gave an idea of the human interpretation of the figures on the illustrations. Mr. Fleming had also mentioned the very serious difficulty of getting satisfactory measurements of noise. To add to the problems that arose for discussion there had been mention of the practical difficulties of providing any effective silencing of aircraft during the very awkward period of take-off and landing.

Those three major items indicated the type of problem which might well be discussed.

PROFESSOR E. J. RICHARDS (*Fellow*): He commented on the use of walls round about aerodromes, and more particularly the use of ground silencing devices of the type which had been tried out in the United States.

The gain which had been obtained by the use of walls in the tests made by Mr. Hayhurst was very considerable, and he felt that insufficient attention had been given to such gains, even though he understood that a wall was being built at London Airport. He pleaded for consideration to be given to the use of such walls, and for the use of running-up pens close to existing concrete hangers, for there were great possibilities there, particularly when a new aerodrome was being laid out. He realised that there were not likely to be any more civil aerodromes in this country, but his remarks applied also to military aerodromes of the future.

In America they had gone to extreme lengths with the muffler type of ground silencer and had effected a reduction of as much as 25 or 30 db. They had put a muffler round the jet, embracing it very closely, and also a muffler around the intake, again embracing it very closely. The total cost of such an installation for a twin-engined aeroplane was of the order of £25,000.

It was very complicated and clearly could not be used under conditions of much traffic and large programmes of running-up on a civil aerodrome. So that he was sure that this type of complicated silencer was not really practicable. Did the lecturers feel that way also?

There was one advance which had been made in Great Britain, however, which might well be borne in mind in future muffler or silencer designs. As a result of research into the basic causes of noise production they understood more about where the noise came from, and should now be more capable of developing ground silencers which were half way between noise suppression devices and the older silencer systems. For example, if the low frequency noise came from burbling downstream, rather than use a fairly large mass of acoustic material to get rid of that noise it would seem quite sensible to have some suppression scheme to decrease the low frequency content by raising its frequency. Such devices on the aircraft must be small, but there was no similar limitation to prevent altering its scale when used in the ground installation. A honeycomb of fairly large mass, for instance, might well cut down the low frequency noise and raise the general frequency and, of course, the attenuation would be very much greater in that particular case. A silencer which was a combination of acoustic silencing material and in addition sound suppression devices should be considered very seriously. He would be interested in the views of the lecturers and other speakers.

JOHN BRISCOE (Ministry of Civil Aviation): Quite a lot had been written about decibels and phons in the papers presented, but nobody had touched on the problem of measuring how much noise caused annoyance; particularly the intermittency of the noise. Had the lecturers any ideas about measuring the nuisance from that? One remembered how annoying were the pulse jets of the V1. With the helicopter or Autogiro they heard the phut-phutting of the blades—presumably it was the blades—although the noise level was not very high. During the recent trials on the South Bank a large part of the Festival site buildings was being knocked down by means of pneumatic drills and there was practically no difference in the readings of the noise meters on the site when the pneumatic drills were operating and when they were not. He considered there was a real problem; in America there were at least two helicopters running with pulse jets and some means was needed of describing the annoyance they caused.

The problem of aircraft noise from the customers' point of view was peculiarly one for civil aviation. It seemed to be the policy for the military to go to the wilds of Salisbury Plain or even Bedfordshire; but a civil aerodrome must be near a centre of population and, looking to the future, helicopters would lose their entire advantage if they did not operate right into the city centre. A jet aircraft could operate from a runway about 700 ft. from a house, but a civil helicopter would often operate only 150 ft. horizontally from a house. Helicopters might be operated from roof-top sites, but those sites were liable to be only 80 ft. above the ground, owing to restrictions in the London Building Act, and less than 80 ft. above bedroom levels. He believed the average level of noise in the Strand when 'buses were passing was 85 db.; only an aircraft manufacturer would think it reasonable for people to become accustomed to louder noises, especially after working hours, when the average noise level was low. It seemed that if helicopters were too noisy they would not be allowed into city centres at all.

The meeting had not really heard about the noise levels down to which any of the experimental work would bring them, and what level was regarded as being too noisy was a matter of opinion. His own opinion was that the maximum that could be accepted at city centres for the operation of helicopters, whether piston engine or jet driven, was 85 db. at 150 ft., and it would be interesting to know whether those manufacturers who indulged in the noisier types of helicopters considered that they could get down to that level.

DR. A. J. KING (Metropolitan-Vickers Electrical Co. Ltd.): He did not know quite what form warming-up pens for aircraft on the ground would take. Sometimes a hangar might be used, with suitable provision for the air to come in and the gases to go out; of course, the same conditions applied to engine test beds.

He had in mind the wide frequency bands that one tried to cover in dealing with jet engines, bands certainly as low as 100 cycles per second and up to 10,000 cycles per second. The 100-cycles wavelength was 11 ft., and the 10,000-cycles wavelength was of the order of one inch. To cover that very wide frequency range adequately without multiple bends, in his opinion*, the width of the air passage should not be greater than two wavelengths, for otherwise the sound would go down the middle and would not be absorbed, and the lining should not be less than one-twelfth of the wavelength in thickness, or there would not be much absorption. Where there was a wide duct sub-divided by splitters, the thickness of the splitters must be twice that of the lining, *i.e.* one-sixth of a wavelength. Those figures were a rough guide in practice, the complete mathematical solution† being very complex.

The other important factor was the economic one of the ratio of air passage width to the thickness of the porous absorber or lining, because that affected the economic scale of the problem. If one were considering frequencies up to 10,000 cycles per second, the air passage should not be of greater width than 3 in., and down to 100 cycles per second the lining thickness should not be less than one foot, and splitters not less than 2 ft. This gave a space factor of only 11 per cent., making a very uneconomic arrangement, with much larger ducts than would otherwise be necessary.

One method was to combine two absorbing systems, one for low frequencies, followed by another for high frequencies. The low frequency one might have splitters of the order of 16 in. thick, with 16 in. air space, followed by splitters 3 in. thick and with 3 in. air space.

*A. J. KING (1948), *et al. Engineering*, 30th January and 13th February 1948.

†R. A. SCOTT (1946). *Proc. Phys. Soc.*, vol. Lviii, p. 358, 1946.

The space factor with that arrangement was 50 per cent., which was reasonable, and the whole wavelength range was covered much more adequately. It had been claimed that one could do equally well by having a wide air space, *e.g.* 16 in. and comparatively thin lining, *e.g.* 4 in., and altering the direction many times in order to encourage cross waves with repeated reflections and absorptions. He was awaiting the results from an installation to compare the two methods.

W. J. A. SAWYER (Bristol Aeroplane Co. Ltd.): There seemed a possibility that they would be faced one day with having to achieve a certain standard of quietness. He spoke, not as a physicist, but as a mechanical engineer and more particularly as a test engineer; was any sort of readily available and reliable assessment of noise nuisance ever likely? He had some conception of a decibel, but found it difficult to get the idea of the " weighted " response.

When measurements were made, one appreciated the immense effort that went into them. A large amount of apparatus was used by a highly skilled staff, who took readings over the whole spectrum and produced curves which, to the uninitiated, seemed very much the same, although the noises might have sounded rather different.

He appreciated that there could be no such thing as an average person as regards susceptibility to noise, but was it possible to simplify the measurements to, say, intensity readings in certain selected octave bands so that some standard of assessment could be universally available?

The volume of noise as well as intensity seemed to be important and when from time to time complaints had been received it had often been the case, especially at night, that there had been a number of plants running without any one being particularly offensive.

Again, one could make far more noise during the week than on Sunday mornings, which again emphasised the difficulty of creating any standard.

From time to time, when endeavouring to assess the noise made by the engine tests, it had been found that the noises made by trains passing along the local railway line were certainly louder than those produced by the tests; and when a locomotive was blowing off steam in the siding the noise was far worse; yet people did not now take any particular notice of the locomotives and trains. Again, people living in houses adjacent to main roads complained of vibration due to test beds, although any vibration that the tests produced would be air-borne; and when observations had been made in the houses, the passing of a lorry resulted in heavier vibration than anything the test beds could produce.

D. RENDEL (Royal Aircraft Establishment): The question of the subjective nature of noise was leading to perhaps wider implications than some speakers had suggested, because all their measurements were limited by the response characteristic of the microphone and its associated electrical system. There was no doubt that to many people there were effects—he would not call them noise oscillations—which were outside the range of the microphone. Many of these and particularly those in the low frequency band, were far more irritating than the measured effects.

The first thing to find out was what they meant by " noise." When something dropped on to the floor it made a noise; and nuisance was caused by many things apart from noise. Noise could be measured in decibels, but not its effect. The three phases should be considered—the production of the noise, its transmission and the result at the other end.

At the morning session of the symposium the production of noise had been discussed, and he felt there was danger of confusion even there, in connection with noise produced by air, *i.e.* through jets. In the afternoon they were more concerned with air as a transmitting medium. Noise might be transmitted not only by air, but also by a structure or the ground or other things; it might be transmitted at one stage by air and at a later stage through the walls of a house. There was great need for a clearly defined picture of the irritation caused by noise, starting with the source of noise, then the transmitting media—which included the question of attenuation—and coming on to the most difficult part, the effect on the recipient, which they had no precise means of measuring. Noise affected people's bodies, perhaps mainly the ears, but it might also be received through the bones. There was danger of losing sight of the main consideration by talking about the detail aspects of the mechanisms of production of noise.

MR. SAWYER: He was glad that attention had been drawn to the psychological effect of noises radiated in different parts of the system—the nuisance value. Certain types of aircraft produced very considerable high frequency noises which were heard as a scream, and it might be a particularly offensive form of noise. It was clearly marked with the centrifugal engine, and an aspect of design came in there. With an installation with a forward-facing intake and a fairly direct duct to the intake, the proportions more or less took the form of a horn; there was a fairly directional effect, and unfortunately the radiation efficiency was raised at the same time. Perhaps that was why the approach of the Comet appeared to be particularly marked; it was just pointing downwards. Another jet which seemed to be coming into service was a particular offender in that respect. With the jets on the Princess flying boat, where the air took a fairly circuitous route into the intake, there was quite an improvement. Probably that improvement had to be paid for by a little loss of ram, but a good deal could be recovered by a suitable chamber design. An aircraft which incorporated an installation of that kind might be more acceptable from the point of view of the noise on the ground than were those in service at the present time.

PROFESSOR T. R. CAVE-BROWNE-CAVE (University of Southampton, *Fellow*): The discussion was, as usual, coming quite correctly to the conclusion that the thing which really mattered was the effect of the various physical noises on the nervous systems of the victims. His experience had been that if they could make the victims understand the nature of the noise, and could

make them appreciate that it was largely inevitable but that they were doing their best to reduce it, a very large part of the offensiveness of the noise was removed; and it was the offensiveness of the noise which really mattered.

He had had to deal with a number of complaints of noises produced by aircraft engines under test, and in nearly all cases the complaints had gradually disappeared, partly because selected victims had been shown what was being done and it was explained to them that fairly elaborate precautions were taken to screen them from noise as far as possible.

Until comparatively recently there had been a Noise Abatement League, with whose policy he differed fundamentally, although he was a member of their Council and Chairman of their Technical Committee. Their policy seemed to be to explain to people what a dreadful thing noise was and how important it was that noise should be reduced. Inasmuch as their object was avowedly to reduce noise it seemed wrong to do anything to increase offensiveness which was the most important factor.

He wished therefore to emphasise a very important point. It was the duty of engineers and scientists to reduce noise so far as reasonably possible. Technical discussions like the present one were most valuable. They must, however, keep clearly in view the real objective, which was to reduce the damage and distress caused to the general public by the noises they made. It was specially incumbent on them as sensible logical people not to moan about noise *in public* thereby making many people excessively noise conscious and indeed magnifying the offensiveness.

J. F. M. ORAM (Bristol Aeroplane Co. Ltd., *Fellow*): There was more in the question of noise abatement than the engineer could reasonably deal with. Perhaps the problem might best be tackled by a joint effort with the medical people. After all, scientists were best able to study the characteristics and physics of the noise source, but were not well qualified to assess the irritation levels of that source. The medical worker, on the other hand, was concerned with the human body and its nervous system. Following on the idea of establishing some standard for the irritation level, perhaps the engineers could help best by developing an instrument of an integrating nature which the medical men could use to measure the cumulative effect of the noises.

T. D. READER (de Havilland Engine Co.): He felt that speakers had overlooked one of the most annoying factors in connection with noise, and that was the factor which prevented them from conversing. They should try to eliminate noises which coincided with voice frequencies. Noises which interfered with conversation were of a musical nature rather than a random nature. If they could reduce the noise intensity within their compass of speech they would go a long way towards removing its annoyance. A note of a whining nature was much more irritating than a general roar. If they covered their ears for a while when in a busy street and then uncovered them they appreciated the extent to which random noise could be tolerated.

A. STEPAN (Fairey Aviation Co. Ltd.): He had had a certain amount of experience of the annoyance caused by noises due to vibration; he had run pressure jets on the test bed and afterwards a two-bladed rotor, and if he adjusted the jet noise so that the measured noise on the test bench was the same as the measured noise level of the rotor, nine out of ten people would confirm that there was much more noise when a two-bladed jet rotor with two pressure jets on the ends was going round. This applied especially for low rotor revs.

He stressed that a jet on the bench and a jet rotating must be of just the same measured noise level. At the same pressure it would make less noise while rotating, due to the relative velocity of the jet through the air, but if he adjusted the pressure so that the measured noise was the same, then the intermittent noise was much more irritating than a constant roar. That confirmed more or less the feeling of most of the previous speakers.

MR. FLEMING

A great deal of the discussion had turned on the nuisance value of a noise and on the question as to whether that nuisance value could be measured. Of course, the nuisance value of a noise differed with different people; it differed also according to the circumstances in which it was heard. The only way in which to assess it would be to get a very large number of observers to listen to a noise and to say whether they thought it was less or more of a nuisance than some other noise. It would be necessary to have a large number of observers taking part because the differences in the assessment of nuisances by different people were very wide, and it would be difficult to design any objective instrument which would give the same value as the average individual assessment of the nuisance. There were a lot of factors concerned in the assessment of nuisance, which had been mentioned, and with some of them he particularly agreed.

Mr. Sawyer had mentioned the volume of noise—by which he meant, presumably, a wide distribution of the source. A similar condition arose when the sense of directionallity was absent. In a certain case a noise which appeared to be coming from all around was considered more annoying, by a complainant, than a louder noise the source of which was readily localised.

Any noise having a distinct frequency was much more likely to attract attention, and be regarded as a nuisance, than noise of a more indiscriminate nature. The latter was more easily lost in the general background of noises, but noise of a steady pitch, or particularly one which was beating, called attention to itself and, even though it was of lower intensity than the background, it was often regarded as a nuisance.

He agreed with Professor Cave-Browne-Cave that psychology could help a lot; if one could explain to people that steps were being taken to reduce a noise,

then whether or not it was reduced, the explanation would help a great deal; they became much more annoyed by a noise if they thought that one was not sympathetic or was not making any effort to reduce it. But he did not think that any amount of publicity of that kind would be enough where a noise definitely interfered with conversation; if people had to stop speaking because of a noise, if it interrupted conferences and things of that kind, he did not think they could explain it away, it must be reduced. However desirable it was to give a precise figure to a nuisance level, he did not think it was so very important if they could not do so. If a noise were a nuisance it must be reduced and, they must learn how to reduce the physical intensity of the noise in order to reduce the nuisance value.

A great deal of work had been done on the problem of interference with speech and it was possible to estimate from the objective analysis of a noise just how much it would interfere with the intelligibility of speech. The lower frequencies did not interfere with speech so very much, nor did the very high frequencies.

Dr. King thought that it would be a good thing to design silencing ducts for test houses with the splitters 16 in. thick and a 16 in. air space; he had no doubt that they would be very good ducts, but he had never been able to persuade anybody to do such a thing; it did not seem to him to be an economic proposition.

MR. HAYHURST

The problem in this and other countries of the construction of test houses was a very different one from that which was worrying airport authorities. A test house had, by law, to be silenced to a much finer degree than that to which they had ever hoped to silence airports. Consequently the airports could get away with a reduction of 25 phons and be acclaimed public benefactors, whereas Dr. King and his colleagues had to attain a reduction of something like 70 phons or find themselves in the High Court.

He was quite certain the airport authorities had been so much worried during the past two or three years about the complaints concerning noise that they would certainly take notice of any and every possible method of obtaining noise abatement.

The operational practicability of using large silencers was a matter on which airlines' opinions would have to be sought. They would be wise to think now about the problem since events might lead them to be forced to take some action imposing restrictions on their operations.

GENERAL DISCUSSION

DR. G. E. BELL presided at the Final Session, which was devoted to general discussion on points arising out of any of the papers presented during the day. It also afforded the opportunity for those who had spoken earlier to express second thoughts or to raise new points of discussion.

G. M. ETTINGER (Air Trainers Ltd.): Vibration was as much a nuisance to the aircraft as to the passengers, in particular, the effect of low frequency vibrations on the serviceability of aircraft instruments and electrics. He urged airframe manufacturers to consider means for attenuating structure-borne vibrations from piston engines before they reached the fuselage. He thought that a decrease of even a few decibels of low frequency disturbances in aircraft would reduce the probability of instrument failures and might make a substantial contribution to aircraft safety.

DR. KING (Metropolitan-Vickers Electrical Co. Ltd.): He hastened to correct an impression given by Mr. Fleming with regard to splitter design. In his earlier contribution he had given the reasons leading up to a narrow air space and thick lining and had concluded that that was uneconomic. He had followed that with a plea for a two-stage filter with wide air spaces and thick linings or splitters to deal with low frequencies, and narrow air spaces and correspondingly thin linings to deal with high frequencies.

The use of walls or barriers to reduce nuisance from aircraft engines which were warming up on the aerodrome was possible and had been found to give useful attenuation in certain cases. However, a mathematical investigation* had shown that little attenuation would result if certain conditions were not fulfilled considering a source of noise at ground level near to a wall with a person listening at a point some distance away horizontally on the other side of the wall, the noise reduction was dependent almost entirely on the height of the wall in wavelengths and the angle into the sound shadow. If one were situated in a high building or the source were raised above ground level, the effective height of the wall and the angle into the sound shadow would be lessened and the attenuation correspondingly reduced. It was important to remember that when considering the attenuation that could be expected from the use of barriers.

He was very diffident about saying much about nuisance because it was so intangible and they were apt to get out of their depth. Some people were already a little worried with the existing units, phons and decibels, and to introduce another unit would complicate things a little more. It was a fact, however, that the phon scale of equivalent loudness did not give a very illuminating impression to a person of the magnitude of a sound. If a noise were reduced from 100 to 90 phons, some people would say that it was just a 10 per cent. reduction. Actually, however, it was very much more, being of the order of half the loudness and, put in that way, it sounded very much more attractive. However,

*S. W. REDFEARN. *Phil. Mag.*, Ser. 7, vol. xxx, p. 223.

it was not that one was just trying to sell methods of reducing noise and to make one's wares sound more attractive. His company had done a lot of work, and work had been, and was still being, done at the National Physical Laboratory on the relationship between the phon scale of equivalent loudness and what might be called a scale of true loudness. If a noise were reduced to half its original loudness as judged by representative persons, the question was by how much it had been reduced in physical units, as in that way it was possible to build up a true scale of loudness as opposed to the decibel scale of sound level and the phon scale of equivalent loudness. In the Metropolitan-Vickers laboratories at Trafford Park investigations* in 1930-34 on a number of people had shown that loudness approximated to a 5th power law of phons. More recent work suggested that loudness in sones was well represented by antilog [(Phons − 40)/30].

In the U.S.A. a similar relation between sones and phons was determined experimentally and adopted† as a standard. The question of a British standard was under active discussion and in due course it was expected that a truly representative scale would be evolved from the evidence which was being accumulated. It would then be possible to quote the loudness of noises in sones and be sure that the numbers used would give a truer impression of relative loudness than previous comparisons in phons or decibels.

MR. FLEMING: He apologised to Dr. King for having misinterpreted his remarks on the absorbent splitters, but he had gathered the reference was to 16 in. thickness of material and 16 in. air spaces for the low frequencies and 3 in. thickness and 3 in. spaces to deal with high frequencies. The practical difficulty of persuading people to do that sort of thing was that they could not see how they could be expected to maintain splitters 3 in. apart. He wondered whether others would give their opinion on such a type of construction.

DR. KING: For the 3 in. splitters and air spaces, only a short length, *e.g.* 5 to 10 ft., was necessary for adequate attenuation at frequencies above 500 c/s. For the 16 in. low frequency sections, there was room to get along the air spaces for erection and maintenance and to get to the space between the low frequency and high frequency splitters. They might have to be 10 to 20 ft. long for adequate attentuation at frequencies up to 1,000 c/s.

A. E. WOODWARD-NUTT (Ministry of Supply, *Fellow*): He was under the impression that one way in which to tackle the problem of running-up aircraft engines at civil airfields would be to arrange pits or bays below ground level in which engines would be run up for maintenance purposes, with some kind of reflector by which the noise could be reflected upwards. Was that possible, and what happened to the noise if it were reflected upwards; did it come down again anywhere?

Was any part of propeller noise due to vibration of the blades themselves, or was it due entirely to the passage of the blades through the air? If a large part of it were due to the vibration of the blades themselves, one would expect a great deal less noise with propeller-turbine engines than with reciprocating engines.

In his view the sonic bang story had been grossly oversold, and he did not think it would be anything like the nuisance that most people suggested. He considered that a very long time would elapse before they were driving about the skies at low altitudes at supersonic speeds and the nuisance from high level "bangs" could be looked after by normal Service discipline; it might be 20 years before the idea, mentioned by one speaker, of "a civil aircraft cruising peacefully and supersonically at 20,000 ft." materialised.

Was there any serious prospect of experiencing ultrasonic noise from aircraft, and if so, what would be the effect on dogs and other animals?

MR. HAYHURST: The conclusions of the mathematical investigation into acoustic screening by walls or barriers, to which Dr. King had referred, were not supported by the results obtained in the full-scale experimental work at London Airport. A notable reduction had been obtained over the whole frequency range. He agreed that the reduction depended on the angle subtended at the source of sound by the barrier and this was relevant to Mr. Woodward-Nutt's point about the pit. If, instead of having the aircraft on the surface and with a wall in front, there was a slope downwards and the aircraft was at the bottom, the effect would be the same. There would, however, be the serious operational problem of getting the aircraft down there and up again.

If noise came against the wall, some of it would be absorbed and some reflected. The noise reflected behind the aeroplane would be added to the noise behind the aeroplane anyhow, and, assuming the two to be of equal level, would increase the loudness by 3 phons only, which would not be noticeable. If the wall were at such an angle that the noise was reflected upwards they would avoid this negligible 3 phon increase. If the noise were reflected upwards he imagined that it would come down again if there were low clouds in the sky; but these conditions were so variable that it was almost impossible to predict the results.

R. N. EVANS (de Havilland Engine Co. Ltd.): He lived three or four miles from Northolt, which meant that he heard a moderate amount of noise from aeroplanes coming in to land; he happened to be in the wrong direction in that respect. He did not complain, for it was a reasonable amount of noise, but it was a nuisance occasionally. On occasions when he had been to Northolt, however, he had felt sorry for those who were living very close to the aerodrome. Although one could do something by explaining to people what one was doing and that everything possible was being done to reduce the noise, he did not feel that that was sufficient if the noise level were really high. From the figures quoted by Professor Richards for possible future aircraft, it would seem that unless something very ingenious could be produced to reduce the noise substantially, a sort of desert area for

*B. G. CHURCHER. *J. Acoustical Soc. Am.*, vol. vi, No. 4, p. 216, April 1935.
†A.S.A. Z. 24.2: 1942.

about four miles radius around an aerodrome would be necessary, which was rather drastic.

He had wondered whether an underground chamber could be provided for running-up aircraft engines; it would seem rather promising. He did not feel that they would gain anything by adopting the suggestion, illustrated by Mr. Hayhurst, of taking the aircraft down to a low level, but he wondered whether it was possible to have an underground testing chamber fitted with a roof. The whole thing was getting rather expensive; but was it not really necessary?

H. CAPLAN (British Aviation Insurance Co. Ltd., *Graduate*): Some of the things which had frightened Councillor Yates earlier in the Discussion, such as the breaking of windows, were the sort of things which frightened his company also, and in the past he had prepared reports to underwriters on the probable effects of aircraft noise.

The aerodrome operators were afforded substantial protection for acts of nuisance in respect of noise and vibration caused on aerodromes. All credit was due to the Ministries concerned, therefore, that they were trying to eliminate or reduce noise, even though they need not do so.

It was also provided by the Civil Aviation Act, 1949, and by subsequent Regulations that no action should lie with regard to nuisance (or trespass) by reason only of the passage of aircraft over land. There was no mention of the point that it might cause some structural vibration. There might be other problems; children might not be able to sleep, chickens might stop laying eggs. Those were serious problems, and his company's problem was that some policies seemed to offer hope to the operators that they could recover the cost of any damages which might be awarded against them by the High Court. Hence the company was vitally interested and was grateful that so much talent was devoted to the altruistic purpose of reducing noise nuisance.

His main reason for speaking, however, was to drop a small bombshell into the sonic bang. At one time he had had the privilege of hearing lectures by Mr. Lilley on such subjects (aerodynamics), and he wished to take up the point concerning the attenuation of various bits of atmosphere in particular sorts of turbulence. They were told that there was a rumble down the middle which was picked up as occurring downstream. There might be a simple explanation, that if there were high frequency sources of sound they might decay rapidly, but if there were low frequency sources passing they would not pick them up until the others had faded away.

There were probably shock waves coming off supersonic aircraft and they might produce a pressure impulse on a man's ear. That was not a bang. A single impulse, no matter if it were of 130 db. intensity, which he believed it had been said was equivalent to 1 lb./ft.^{2}, was not a bang. It might cause pain or be a nuisance, and if one suffered from catarrh it was a greater nuisance. Outside the audible frequency ranges of from 15 to 15,000 cycles per second, a single impulse was no bang.

Only that afternoon he had checked the point with his office. They had telephoned a medical superintendent of the B.O.A.C., who in turn was good enough to consult an ear specialist; he confirmed that a single impulse would be felt by a human being as pain, if it were sufficiently intense, but not as noise.

Shock waves, be they single or multiple, could not be produced in the audible frequencies just as shock waves; that was impossible.

He could not offer a great deal in return, but he suggested the accumulation point of view, where there was a continuous emission of noise—the "noise accumulation theory" was perhaps the most fruitful.

Questions had been asked as to how noise could be measured. The Americans had explored the matter, and apparently the best way in which to measure it was to note the number of comp'aints received each week. He meant that seriously. One company had fitted up a light aircraft with all the noise suppression devices they could think of and had flown it for several weeks. They had also collected about a thousand sample opinions beforehand and a thousand afterwards. The people interviewed had noticed the noise, but many of them were more annoyed to have been asked about it than they were by the aircraft flying around.

He did not think sonic bangs were over-sold; they had not been sold as nuisance value, but just to satisfy curiosity.

C. H. E. WARREN: The question to answer was whether a pressure impulse could give an audible sensation to the ear. He felt that the answer was definitely yes, but preferred to leave it to the medical specialist to furnish an authoritative statement to this effect.

As to whether or not the sonic bang had been oversold, a letter had been published in "The Times" during the previous week, in which perhaps it was. On the other hand, they must not under-rate the nuisance it was liable to be. He agreed that they were not likely to have civil aeroplanes flying at supersonic speeds at 20,000 ft. for another 20 years, but he hoped that military aeroplanes would be doing so before then, and unless something was done there would be a nuisance value from them. The sonic bang was a very sudden noise, and he believed it was more disturbing than something for which one was prepared. For instance, at Farnborough sonic bangs were heard occasionally, and one could visualise a chemist, making some measurement with great care; a sudden bang might cause him to jump and spoil the whole of his experiment. A case had been reported of a trainee fireman, who in the course of his training was sent up the escape. When he was at the top an aircraft produced a sonic bang; the fireman was frightened and came down quickly, and he had to be treated for shock. The point seemed to be that if one were doing something whereby one was tensed, a sonic bang could be very disturbing.

PROFESSOR RICHARDS: He corroborated Mr. Warren's remarks on sonic bangs; two such bangs were heard in Southampton and district. People out in the

wilds did not expect things like that; lots of the people were very much put out and did not like the experience.

There was no question that in an aeroplane driven by piston engines with reciprocating parts there must be vibration. They could expect the instruments to fracture and hydraulic pipelines to fail from time to time. With the propeller-turbine and the power jet, however, they could expect a considerable improvement, and unless the propeller on the propeller turbine were made to rotate too rapidly it was quite likely that it would have a very much longer life than a propeller on a piston engine.

A matter to which particular atttention should be paid was the noise from jets causing vibration. Fig. B showed measurements made in U.S.A. There they had had trouble with fractures of secondary structures near the jet pipe, and in Great Britain there had been trouble with secondary structures some distance downstream, where the jet ran in very close proximity to some part of the structure.

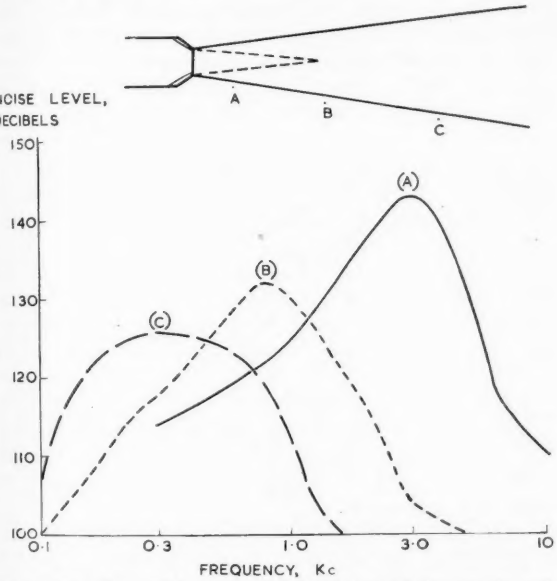

FIGURE B. Comparison of the intensities and frequencies of noise measured at three points close to the boundary of a model jet.

In the figure, the noise level was plotted in decibels against the frequency at points *A*, *B* and *C*, going downstream from the jet. The highest noise levels appeared very close to the jet, according to line *A*, and the peak was fairly well marked. So that if the natural frequency of a piece of the structure or some equipment coincided with this peak something might fracture. Going rearward along the fuselage the frequency came down nearer to the frequency at which fairly large masses of structure could be influenced by vibration and fatigue. For instance, if the point *B* were getting towards the tailplane, the frequency would come down still more and the energy input, if the jet were very close to the fuselage or the tailplane, might be such as to cause, in time, the failure of some part of the structure. It was worth while to observe the type of frequency variation in the downstream direction, so that in putting in the equipment and designing the structure they would bear in mind the type of vibration arising at the various points. There was a great need for more figures along those lines, to assist them to arrive at the best means of guarding against trouble. Was it best to move the jet slightly outwards; or on the other hand, was it best to alter the structure and get right away from the peak frequency? He did not know how much could be done along those lines, but the matter was worth thinking about. The vibrations were outside the jet itself, but they were influenced by the jet noise.

He wondered if they were using walls properly. It might be worth while to have the jets running parallel to the wall.

MR. HAYHURST: He understood that if a wall were used, the present scheme was to put the aeroplane in nose first or tail first. If the aeroplane were placed alongside the wall, some of the engines would be at least the semi-span of the aeroplane away from the wall. The geometry of typical current aeroplanes meant that these engines would then be farther from the wall than they would be with the aeroplane in nose first or about the same distance away than with the aeroplane in tail first. There would therefore be less abatement than the optimum, but probably no less than would be obtained with the aeroplane tail to the wall. These abatements would have to be considered in relation to the operational problems associated with the different positionings of the aeroplane.

DR. E. G. RICHARDSON: Was it considered a practical proposition to have the aeroplane oriented in such a way that the jet was blowing against the wall?

THE CHAIRMAN (Dr. Bell): The wall must be constructed to withstand that velocity.

DR. G. S. HISLOP (Fairey Aviation Co. Ltd., *Assoc. Fellow*): He would agree wholeheartedly with Mr. Briscoe in emphasising the importance of noise in civil helicopter operation. It was quite clear that if helicopters could not go right into the centres of cities they would not serve a useful purpose so far as the major European airlines were concerned. The ability to operate without restriction was therefore of vital importance.

They had thus to set up a standard of noise level which would be acceptable to people on the ground without imposing an excessive penalty on the aircraft. Reference had been made to a suggested maximum overall noise level of 85 db. at 150 ft. from the aircraft, but he felt that this was altogether too high a standard, because it had been shown that the noise from current small helicopters was of the order of 94 db. when overhead at 200 ft. No one could fairly say that the latter noise level was excessive, especially if applied to a large transport vehicle. He would advocate adopting a figure of this level for civil transports where city centre operation was envisaged.

As an illustration that current helicopter noise was

acceptable even during the dead of night in built-up areas, there was the night mail service in East Anglia run some three years ago by British European Airways, between the cities of Peterborough and Norwich. It was run during the winter, the machines leaving Norwich at about 10 p.m., arriving at Peterborough at 11 p.m., leaving again at about 2 a.m. and finally landing at Norwich at about 3 a.m. The aircraft landed in an area within about 100 yards from dwelling houses and a nursing home. The service was operated every night for six months and there was no complaint whatever about noise, although the level must have approached 100 db. at times.

That experience was in line with the argument put forward by Professor Cave-Brown-Cave, that if the people in the area knew what the aircraft were doing and they also knew that the operators were making every eflort to reduce noise to the minimum, then they would be very reasonable in their attitude.

He understood that a worker named Beranek had evolved a weighting system for a given noise spectrum which resulted in a number—the Beranek number—giving a simple yardstick by which to assess the nuisance or interference effects of any noise, however complex. Did any of the noise authorities present consider it a satisfactory standard? If not, was there any alternative, other than the simple decibel or phon rating?

He had heard the very interesting remark that to a passenger in the cabin of a Comet the general impression was that it was quiet, but when one spoke it was realised that, whatever the intensity and frequency of the noise present, it had a very deadening effect on the speech frequencies. Such an effect would be significant in setting a standard of acceptable cabin noise level in the speech frequencies. A diagram of acceptable cabin noise level plotted against frequency was given in the paper by Mr. Greatrex, who suggested that the R.A.E. standard was too severe and put forward a proposal allowing a greater level of intensity in the speech frequencies. If the experience of the Comet passenger were regarded as representative, then a lessening of the R.A.E. standard might be mistaken—at least in the speech frequency band.

MR. FLEMING: He was not quite sure which figure was referred to by Dr. Hislop as having been proposed by Beranek. He had proposed a method of calculating the loudness from an objective analysis of the noise.* Further, a comfortisation factor had been proposed in the U.S.A.

He had also simplified, by the use of charts based on the work of French and Steinberg,† the calculation from the spectrum of a noise, of the reduction it produced in the intelligibility of speech.

H. GIDDINGS (Bristol Aeroplane Co. Ltd., *Assoc. Fellow*): No reference had been made to supersonic propellers. There were no examples in this country so far as he was aware, but quite a lot of work was being done in the United States, and Professor Richards, in his paper in the May JOURNAL had given a curve relating to a supersonic propeller, suggesting that the noise intensity level was of the same order as that of the pure jet. He had not had the opportunity to look up the references given there; what were the conditions, particularly the speeds? What were the rotational speed and the forward speed, and was the propeller a properly designed supersonic propeller or a subsonic one run at high speed for test purposes?

Also, had work been done to relate the noise intensity with the separate rotational and forward speed components, and also with the blade thickness/chord ratio?

PROFESSOR RICHARDS: The noise was worked out for the same thrust of the propeller as for the equivalent jet aeroplane; he believed the thrust was 20,000 lb. but he did not know the r.p.m. He believed a supersonic propeller was used, but he was not sure of the thickness/chord ratio, and possibly the noise levels arose from flutter, as one would have expected to happen with very thin blades. He would find out a little more about it and would get into touch with Mr. Giddings.

MR. LILLEY: Although the noise from the rotational motion of the propeller had been calculated, he did not think that this was so for the noise due to forward motion of the propeller.

With reference to Mr. Caplan's remarks about the high and low frequency noises coming from the jet, the matter could be explained fairly simply. The thickness of the turbulent mixing region just downstream of the nozzle exit was small; hence the scale of turbulence was small and the noise generated would have small wave length (*i.e.* high frequency). Farther downstream, after the mixing region had spread to the jet centre line, the scale of turbulence was large and noise generated was then of low frequency.

On the question as to whether in fact they could hear shock waves, he would not attempt to give a complete answer here, since this matter was discussed in some detail in a paper in the June JOURNAL of the Society.† They might like to see four slides reproduced from that paper, showing the shock wave pattern around a small aerofoil which was in turn accelerated from subsonic to supersonic speeds and then retarded back to subsonic speeds.

(1) Showed the aerofoil moving subsonically above its critical Mach number.

(2) The aerofoil had just exceeded sonic speed. A bow wave was formed ahead of the aerofoil and was still of finite extent; it would become of infinite extent only when the flight had continued for an infinite time. The trailing edge shock wave had spread out a little more than in the former slide and there was an approximately normal shock wave in the wake of the aerofoil.

* Ref. 5 of Mr. Fleming's paper.

† N. R. FRENCH and J. C. STEINBERG. *J. Acoust. Soc. Amer.*, 19, 90, 1947.

† G. M. LILLEY and others. *Journal Royal Aeronautical Society*, June 1953. Figs. 22 and 23.

(3) The conditions during the retardation. The bow wave had begun to move ahead of the aerofoil; the trailing edge shock wave was now convex forward, whereas during the acceleration it was concave forward; the rear shock wave could be seen trailing about 5 chords lengths behind the trailing edge. The latter distance was not very significant since it was a function of the given retardation and acceleration.

(4) Showed the aerofoil moving subsonically below the critical Mach number. The bow wave was now far ahead of the noise and was followed by the trailing edge shock wave. Trailing farther behind was the rear shock wave. In many cases of transonic dives, calculations indicated that the rear shock wave would have coalesced with the trailing edge shock wave before the latter moved forward over the surface of the aerofoil.

Provided that it was accepted that supersonic bangs were indeed synonymous of shock waves, a ground observer suitably positioned would hear, in the case illustrated, three bangs, two of them rather strong and the last one a little weaker. In flight for a single acceleration-retardation dive through the speed of sound two bangs might be expected for the reasons he had outlined.

O. THORNYCROFT: He was still a little confused. Was the second shock wave associated only with the transition through the sonic speed and thus, under conditions of continuous flight at supersonic speed, would it trail behind and so eventually disappear?

MR. LILLEY: The approximate normal shock wave in the wake of the aerofoil started to form as soon as the speed of the aerofoil exceeded its critical Mach number and not necessarily at the instant the aerofoil first attained sonic speed. If the aerofoil were accelerated through sonic speed and proceeded at constant supersonic Mach number the rear wave would trail farther and farther behind the trailing edge. After travelling at constant supersonic Mach number for an infinite time the rear shock wave would be infinitely far behind the aerofoil.

ALAN POWELL (Southampton University): Taking the speed of an aircraft into account, if the relative velocity were reduced to half there would be quite a reduction in noise; that was some small consolation. They would have very roughly $(\frac{1}{2})^8$, in other words about 24 db. reduction in noise, which would make things very much easier. The aircraft velocity as well would alter the directionality a little. So they must be careful in predicting the noise in aircraft as distinct from making observations on the ground with a stationary jet.

From the point of view of noise reduction, they had seen the method of introducing turbulence, so that the total noise was reduced as the shear reduced. What was the balance? It was rather precarious; in some cases there was more noise and sometimes there was less, the noise depending on (shear) × (turbulence). But could they get rid of the shear from the start?

If the jet velocity were constant across the exit and then the velocity profile was changed, reducing the velocity gradient from an extremely large to a very much smaller amount, they would expect a reduction of noise, and that was found to be so* (Fig. C). The normal

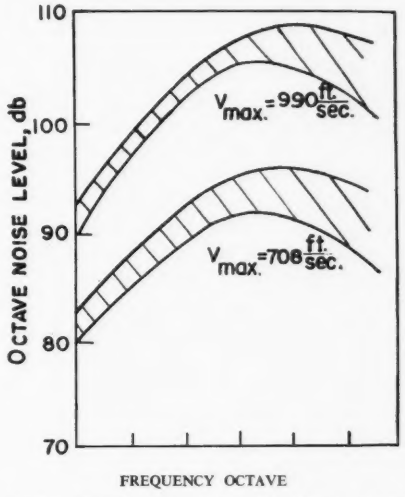

FIGURE C. Reductions (cross-hatched) at two velocities due to reduction of velocity gradient at jet exit.

spectrum was reduced to about the shape indicated. The reduction at the high frequencies was much greater as one would expect, simply because the reduction in shear had most effect in the region where the high frequency noise was mainly produced. In the case illustrated, a reduction of 5 or 6 db. had cost a quarter of the thrust, which was quite impossible from the manufacturers' point of view. But if a comparison were made on the basis of equal thrust, the picture was rather different. If they reduced the gradient near the jet boundary (as in developed pipe flow) and slightly increased the diameter to maintain the same thrust, a reduction in noise level still occurred. If they had a constant velocity across the new larger diameter, to give the same thrust, the noise was reduced still further.

In other words, in comparison with the latter the higher velocity near the centre of the modified jet more than made up for its shear reduction at the edges. A reduction of the velocity by 13 per cent. would bring about a noise reduction of about 4 db. That was quite a small reduction in comparison with the amount which Professor Richards had indicated as being desirable (perhaps 20 db.), but one could see no way of achieving that in one fell swoop and there must be a collection of small reductions attained in different ways. The reduction in jet velocity was possibly one way, particularly for long-distance aircraft, where the heavier engine would probably be offset by decreased fuel consumption. In some engines the profile might be modified as well, giving a further reduction in noise level.

*A. POWELL. The Influence of Exit Velocity Profile on the Noise of a Jet. A.R.C. 15473 (revised).

The pulse jet was very attractive mechanically, but unfortunately it was extremely noisy, due to the pulsation of the jet approximating to a simple acoustic source* and there seemed little that could be done to reduce that noise without preventing it from working at all.

MR. GREATREX: He agreed entirely that, with an aeroplane in flight, when the relative velocity between jet and air was very much reduced the noise would go down considerably. But did not that conflict with Mr. Powell's worries about high pressure ratio effects? It seemed to him that that part of the story, although fascinating, was not really of so much practical importance. He would like to hear more about it, but perhaps it would be best to discuss the matter with Mr. Powell.

T. D. READER (de Havilland Engine Co. Ltd.): By rounding off the velocity distribution curve (Fig. D) one ought to be able to reduce the high frequency noise. That noise was probably due to the extremely small eddies coming off in the region of the tail, due to the very large velocity gradient.

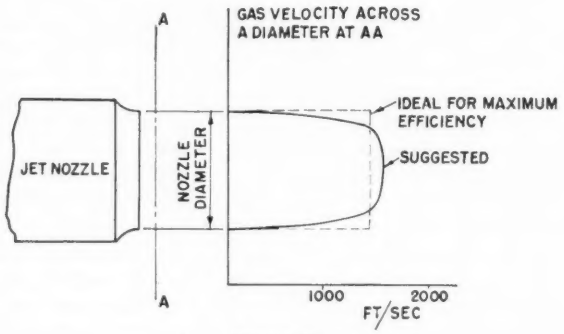

FIGURE D.

All that was done by the use of fingers was to slow down the eddies in the region of the tail and to provide a less steep velocity gradient. It might be that by so doing considerable turbulence would be introduced farther down the jet stream, thereby causing increased burbling. So far as he could see, there was no way of eliminating that low frequency rumble.

No one so far had mentioned the effect of the tip speed of the blades of helicopters on the intensity of ground noise. Normally the helicopter was designed for fairly high tip speed, presumably to keep down the size and weight of the rotating wing. In civil applications it might be desirable to design helicopter blades deliberately for lower tip speeds; was that possible?

MR. GREATREX: In rounding off the velocity profile, for a given pressure ratio in the jet pipe there would be less thrust; and hence increased specific consumption. The aircraft people could say better than he just how much the increased specific consumption would matter to them.

THE CHAIRMAN: The discussion had been of great interest but it was so widespread that there was no question of summarising.

MR. FLEMING: Commenting on one or two points which had not been answered, he referred first to Mr. Caplan's suggestion, for the sonic bang, that the shock wave would not produce an audible sensation. He just could not understand that. It seemed to him that the circumstance which could produce an audible sensation was a sudden pressure change at one's ear. When a bullet passed by there was a sharp crack, similarly the shock wave from an electric spark was audible, and he believed the shock wave from an aircraft was quite capable of producing a bang.

As to the suggestion that 85 db. should be a reasonable limit for the operation of helicopters, and the point that in East Anglia there had been helicopter operations during the night hours without complaint of noise, although the level might have been 95 to 100 db., the frequency of the occurrence of the noise was a factor. Even if it occurred only twice every night, he was surprised that there were no complaints. He felt that a noise level much lower than 95 db. was required where a very frequent service was contemplated (as would normally be the case in towns) if there were not to be interruption of speech in offices around the terminus at each landing and take-off.

*A. POWELL. The Noise of a Pulse Jet. University of Southampton, October 1952. (In the press, *Journal of the Helicopter Association*).

Internal or Residual Stresses in Wrought Aluminium Alloys and their Structural Significance

by

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Introduction

In the design and production of structures it is commonly assumed that the raw material supplied in the form of bar, sheet, forgings and castings is homogeneous, isotropic and stress-free. Some failures in service and more in the laboratory have drawn attention to the possible dangers arising from inhomogeneity, directional properties and residual stresses. It is the purpose of the present paper to review the situation with regard to the last, which the production engineer, who has to cope with distortion on machining, at least cannot ignore.

Part I. FORMATION AND CONTROL

1. Production History of Materials

Most engineering materials, by the time they reach the user, have a fairly long production history which in general can only be varied in minor detail. For example, the production of a wrought aluminium alloy involves melting, alloying, casting into either billets for extrusion or forging, or otherwise into ingots for rolling. Extrusion and forging are generally carried out hot, the billets being preheated before working, and rolling is carried out hot in the early stages and finally cold, with intermediate annealing treatments when necessary. Following these processes, the harder alloys, whose strength depends on precipitation hardening, are heat treated. This final heat treatment consists of soaking at a temperature usually between 430°C and 520°C, quenching, generally in cold water (but there are important exceptions to this), followed in certain cases by precipitation, which consists of soaking at a temperature usually between 130°C and 200°C and cooling in air. After the solution treatment and quenching, these products are usually distorted and it is necessary to correct them dimensionally. With extruded products this is usually done by stretching. Sheet may be "roller levelled," roll-flattened and/or stretched. Forgings are more difficult to deal with, since they are generally non-uniform in section and are not amenable to a stretching operation. They have, therefore, to be corrected by local deformation, such as bending, or otherwise extreme care has to be taken to avoid distortion in the first place.

After complete production by the material manufacturer, extruded and other products are frequently formed by bending or other kind of non-uniform plastic deformation before being put into service.

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2. Formation of Residual Stresses

Most of the production processes mentioned result in residual stress systems of greater or less magnitude. For the sake of brevity, however, attention will be paid to two main sources, *i.e.* heat treatment and subsequent mechanical working and forming operations.

2.1. QUENCHING STRESSES

The origin of quenching stresses can be most easily illustrated by considering the most simple case. If a sphere of aluminium alloy is heated to, say, 500°C. and quenched in water at room temperature, the outside skin will cool before the inner core. As the outside cools, it will try to shrink and thus to compress the still hot interior; the reaction pressure will throw the cold skin into tension and, if the tension be great enough, this material will stretch plastically. Thereafter, as the interior metal cools and attempts to shrink in conformity with the same law of thermal expansion and contraction, its shrinkage will be restrained by the cold skin, so that a state of triple tension will be set up in the interior and will be balanced by two-dimensional compression in the skin. After complete cooling the sphere will remain in a state of equilibrium with the outside under high compressive stress and the inside in a state of tension. This simple explanation, based on consideration of thermal expansion and plastic yield, applies to aluminium alloys and many other materials, but residual stresses can arise from other causes, as, for instance, when dimensional changes occur as a result of phase changes in the material itself.

The problem as a whole is complex, so that at the present time no reliable method is available to compute the residual stress due to quenching from a basic knowledge of the materials. However, measurements have been made by many investigators over a

considerable period of years and detailed knowledge of residual stress systems in simple shapes is available.

Stresses in Cylindrical Bars

The longitudinal stress distribution in cylindrical bars after solution treatment and quenching in cold water has been measured by Zeerleder[1] on "Avional D," a naturally aged Duralumin type material, similar to B.S. 6LI, and the result is represented in Fig. 1. The measurements show a balanced stress system, such that the sum of the compressive and tensile forces is zero; the maximum longitudinal tension is $11\frac{1}{2}$ tons/in.^{2} at the centre, and the maximum compression 7 tons/in.^{2} on

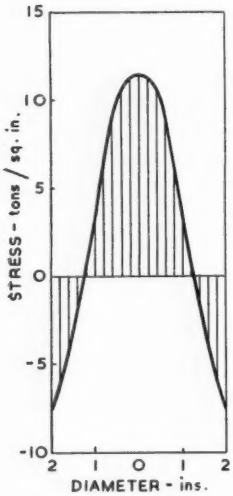


FIGURE 1. Longitudinal residual stresses in Avional D extruded bar quenched in cold water from a solution treatment temperature of 520° C. and aged 24 hours at 50° C. Heyns' method. (Zeerleder[5].)

the outside surface. Zeerleder points out that the values given by his experimental procedure are underestimates, since only unidirectional longitudinal stresses are taken into account. A complete three-dimensional analysis has been made of a number of aluminium alloys by Kempf, Hopkins and Ivanso[2] using a more elaborate technique. Their result for a 4·5 per cent. copper alloy is shown in Fig. 2. The tangential and radial stresses are, of course, equal in the centre. These examples demonstrate that, during the quenching of materials, under conditions which are approximately those of normal production, stresses can be obtained of the order of the limit of proportionality or yield point of the material in its condition immediately following quenching. High stresses can occur in quenched rods of quite small size. For example, Wassermann[3], using X-ray measurements, found measurable compressive stresses on the surface of samples of Duralumin of only 1 mm. diameter after quenching in ice water. The stresses increased with increasing specimen diameter, at first rapidly, then more slowly, to a maximum value at a diameter of about 20 mm. These stresses were surface stresses and are probably limited by the yielding of the material. When three-dimensional analyses are made, it is found that the triple tensile stresses in the centre may continue to increase with increasing size of bar to very much greater values[4].

Figure 3 shows test results obtained from a small square section specimen quenched on two surfaces only, the stresses being estimated by machining off thin layers from one of the quenched surfaces and measuring the resultant distortion, *i.e.* change of curvature of the remainder[5]. This latter test refers to a piece of material 10 mm. thick and further demonstrates that high residual stress can be obtained from quenching pieces of material of quite small size.

Regarding quenching stresses in more complex shapes, it is not possible to make general comments. No satisfactory theory of production of such stresses has been produced to enable them to be predicted with a reasonable degree of certainty and, in general, where doubt exists as to the presence or absence of dangerous stresses, only experimental measurement or actual mechanical testing of the component under working conditions can give satisfactory information.

2.2. STRESSES DUE TO DRAWING AND SINKING

Drawing and sinking are processes generally applied to wire and tube products (sinking being the drawing of tube through an external die and without a central plug).

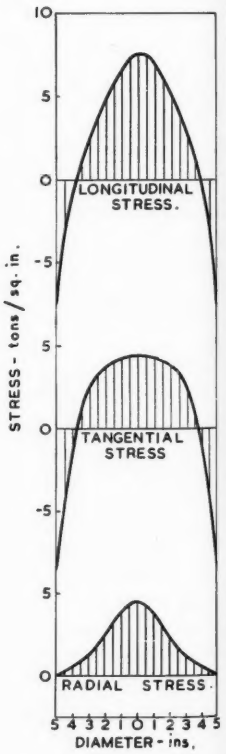


FIGURE 2. Residual stress diagram. Quenched in cold water from 515° C. Material:—Cu 4·5 per cent., Fe 0·75 per cent., Si 0·8 per cent. Sach's method. (Kempf, Hopkins and Ivanso[6].)

They are of considerable importance in the present context, since not only are they applied as a final operation to work-hardened materials, but they are sometimes applied to heat treated alloys following solution treatment, either to increase the tensile properties, or to ensure close dimensional correctness and straightness.

Comparatively little work has so far been reported on the residual stress systems produced by such

operations on aluminium alloys. Work by various investigators[6][7][8] on other materials, however, leads to the following conclusions:

(*i*) Drawing or sinking over a wide range of conditions will result in residual stresses which may be as high, or nearly as high, as the yield stress of the material in the "as drawn" condition.

(*ii*) Such stresses will in general be in tension at, or near, the outer surface.

(*iii*) It is possible by careful control of drawing operations to keep such stresses to comparatively low values.

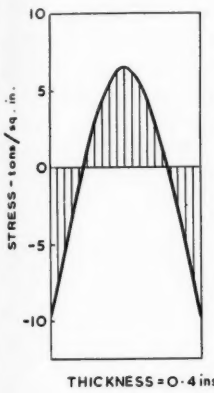


FIGURE 3. Longitudinal residual stress distribution in B.S. 6 LI bar of 0·4 in. square section quenched in cold water on two opposite sides from 497° C.[8].

2.3. STRESSES DUE TO FORMING OPERATIONS

After the normal production of an extruded or rolled product has been completed, it frequently has to be manipulated and formed before incorporation in the structure. With initially stress-free material these forming operations almost invariably result in systems of residual stresses being set up in the material. Where a material is already loaded with residual stresses, such forming operations will largely modify these stresses and may even mask them completely. Where forming operations are very complex, it may be impossible to predict resultant residual stress systems but in simple cases, such as uniform bending, reasonable prediction of the stress system should be possible.

Stresses due to Bending

A method of calculation of stresses in a simple rectangular beam bent under pure couples is shown in Fig. 4. While the beam is still under the bending load, *BAOCD* represents the longitudinal stress distribution in the material, *i.e.* the longitudinal stress-strain curves of the material concerned, with *OH* and *OG* equal to the appropriate values of strain (elastic plus plastic). When the bending load is released, the spring back is represented by a line *FOE*, such that the areas contained by it and the stress-strain curves shall sum to zero and the moments of these areas shall also sum to zero. The resultant internal stress system is given by the ordinates of the curve *BAOCD* drawn about *EOF* as baseline, *i.e.* as shown in Fig. 4*b*.

Residual stresses in this case are limited on the top and bottom surfaces of the beam (*i.e.* those surfaces parallel to the neutral plane) probably to about half the ultimate stress of the material for any bend.

TABLE I

VARIATION OF RESIDUAL STRESS AT UPPER AND LOWER FACES OF RECTANGULAR BEAM

Material:	*0·1 per cent P.S.* 23·4 *tons/in.²*	*U.T.S.* 34·8 *tons/in.²*	*Elongation* 17½ *per cent*
Depth of Beam / Radius of Bend after Spring back	*Residual Stress tons/in.²*		
0·01	9		
0·02	10		
0·04	11		
0·08	12		

A beam of circular section has been considered by Brewer[9]. In this case also there is an upper limit to the stress which can be developed in the corresponding positions, but this will be higher than for the rectangular beam of the same depth bent to the same curvature, because the outermost fibres represent a less proportion of the whole cross-section. In beams of more complex shape, there is no limitation at all, even with large radius bends, and in sections which comprise a heavy flange with a thin web, the position can be entirely different. This can be illustrated by considering a heavy bar with a very thin web attached to one side of it, bent with the thin web on the inside of the bend and thus compressed (it is assumed that the thin web is restrained from buckling). On release, the heavy section will spring back an appreciable amount and it can be seen that, when the web is too thin to prevent the large spring back, it will in fact tear when the spring back occurs. The general case of residual stresses developing at the edge of the web in T-beams has been dealt with by the author in a previous paper[10] and the relation between this stress and the dimensions of the T for a given initial bend are shown in Fig. 5. This calculation is based on various simplifying assumptions including a hypothetical stress-strain curve and elastic spring back and it can be seen that, in theory, stresses higher than the ultimate stress of the material can be obtained. In actual practice, spring back is not necessarily elastic, so the upper part of this diagram is mainly of theoretical interest. It demonstrates conclusively, however, that the stress system again is only limited by the ability of the material to yield.

It is desirable here to comment on the relation between residual stresses induced by bending and the permanent curvature of a beam. This has been calculated for a simple rectangular beam and the results of the calculation are in Table I.

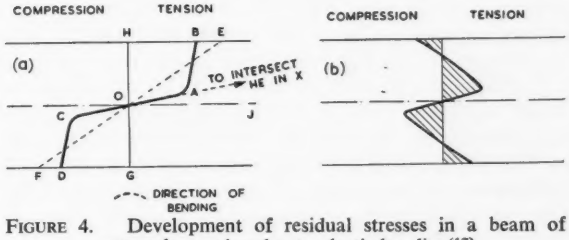
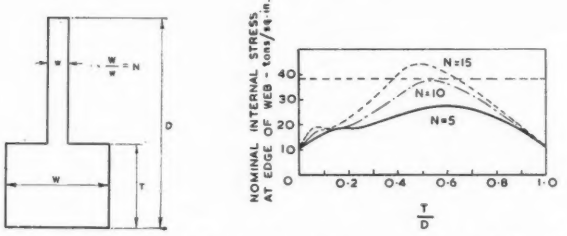
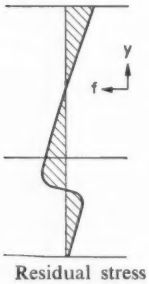


FIGURE 4. Development of residual stresses in a beam of rectangular section due to plastic bending[17].



Variation of residual stress with variation of dimensions of T-beam on assumption of linear spring back.



Residual stress diagram for T-beam shown.

$D/R=5$ per cent. where R=radius of curvature (under load).

Material:—Hypothetical with a stress/strain curve corresponding to:—

$$f=24{\cdot}5\ y^{0{\cdot}148}$$

where f=stress in tons/in.^{2}

y=corresponding total strain (elastic +plastic) per cent.

Ultimate stress is assumed to be 38 tons/in.^{2} equivalent to 20 per cent. elongation.

FIGURE 5. Residual stresses in beams of T-section due to plastic bending[17].

It can be seen from Table I that residual stresses are not proportional to curvature but increase very rapidly with initial plastic bending and then increase very slowly as the curvature is increased.

Stresses due to Stretching

A further method by which residual stress can be induced is by stretching. In general, where material containing a residual stress system is stretched, the extension will markedly reduce existing residual stress systems; the mechanism by which it does so will be described later. If, on the other hand, an initially stress-free material which has non-uniform mechanical properties over the section is stretched, a residual stress system may be induced. This can be illustrated by considering clad sheet. Suppose a strip of clad sheet is stretched and it is possible to plot the stress-strain curve for the core and the cladding separately, as shown in Fig. 6, the stresses in the core and cladding will differ at a given percentage of strain beyond the limit of proportionality of the cladding, the stresses of the cladding being much lower than that of the core. On release, and assuming elastic conditions, the stress-strain conditions during unloading will be represented by curves *ab* and *cd* for core and cladding respectively to a point at which the stress system is balanced and the result will be a small residual tension in the core and a large residual compression in the cladding, represented by ordinates *be* and *de*. The calculated residual stress in the cladding will, however, exceed its yield stress; thus the unloading curve will follow an actual path *cf*, the final values of stress being *be* and *fe* for core and cladding respectively.

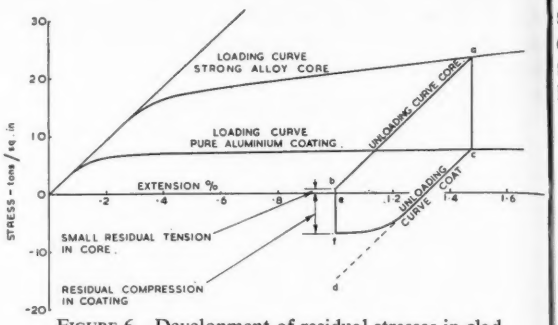


FIGURE 6. Development of residual stresses in clad sheet by stretching.

The case of clad sheet is a somewhat extreme one. A further example would be the case of an extruded bar having a coarse grained outer band with a tensile yield stress appreciably lower than that of the core. In this case also, if the material were initially stress-free, a residual compression would be induced in this outer band.

Pre-loading of sections containing stress concentrations

This method of inducing residual stress can be illustrated by considering a tensile test piece with a round hole. If this test piece is loaded, the stress distribution in the section under elastic conditions is of the form shown in Fig. 7. If the load is sufficiently high and the material at the edges of the hole is stressed beyond the elastic range, the peaks are effectively cut off the

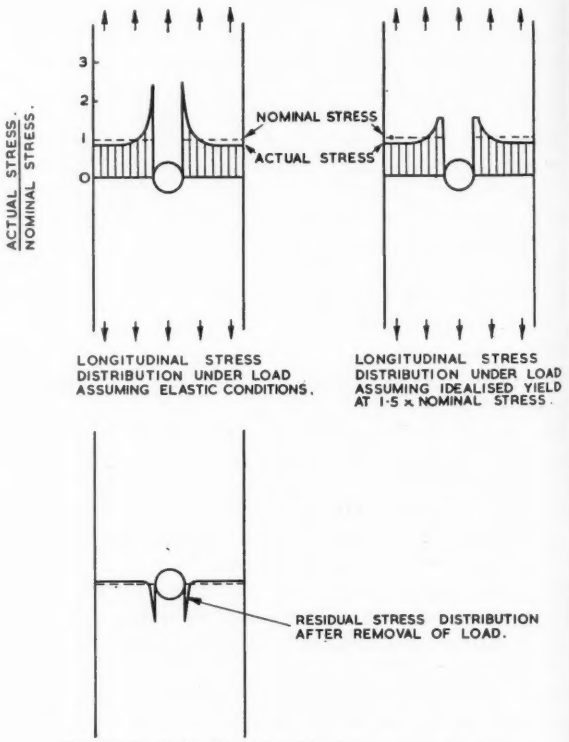


FIGURE 7. Induction of residual stress round a stress concentration by pre-loading.

stress distribution curves. On elastic unloading, this condition will result in compression stresses existing at the edges of the hole, the remainder of the test piece being under a very small residual tension.

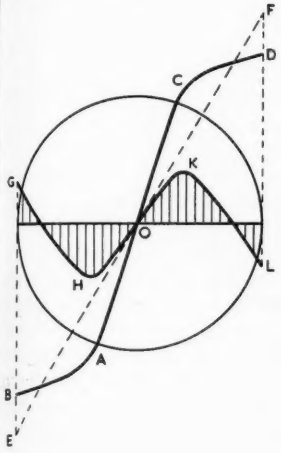


FIGURE 8. Development of residual stresses in circular bar by twisting into the plastic range.

Stresses due to Twisting

Twisting, since it also involves a non-uniform plastic deformation, results in the formation of residual stresses. The method of formation is shown in Fig. 8 for a circular bar. In this case, *BAOCD* (Fig. 8) represents the shear stress distribution over a diameter of the specimen with the load still applied. On release of the load causing the twist, the material will spring back elastically, the spring back being represented by *EOF*, such that the torque released is equal to the torque represented by the original curve *BAOCD*. This will give a residual stress distribution shown by the curve *GHOKL*. This problem, and also the problem of the twisting of a rectangular section, has been dealt with at length in connection with steel springs by Sopwith[11].

Stresses due to Machining

It is well known that most machining operations produce residual stress systems in the material. A number of measurements have been made[12] and it can be generally stated that normal machining operations in which the material is kept adequately cool result in a residual compression on the machined surface, but operations such as grinding, where considerable heat may be generated, result in a residual tension in the surface. It is impossible to generalise on this subject, since actual values of stress depend so much on the details of the particular machining operations involved.

3. The Control and Reduction of Residual Stresses

3.1. THERMAL STRESS RELIEVING TREATMENTS

The most common way of reducing residual stress systems in most metals is by thermal treatment, in general, annealing. This is not generally applicable to high strength wrought aluminium alloys, since the temperature of treatment necessary for large relief of residual stress is considerably higher than the artificial ageing temperature, so that it would seriously reduce the mechanical properties. Some reduction, however, can be obtained by soaking the material at temperatures low enough not to affect the strength too adversely. Fig. 9 illustrates some tests on samples of D.T.D. 364 and 363 extrusions loaded under bending, with a pre-determined strain, in the solution treated state, and then artificially aged while under load[14]. After ageing, the relaxation of stress was measured and it can be seen that reductions of stress between 20-40 per cent. were obtained. Benson[13] using a similar test with samples of material to D.T.D. 410, showed that for material *already artificially aged* no appreciable stress relief could be obtained by further soaking at the ageing temperature and, although soaking at higher temperatures gave a measure

	BS.L45	DTD.363 A
Cu%	4¼	1¼
Si%	¾	—
Mn%	¾	⅛
Mg%	½	2
Zn%	—	7
Cr%	—	⅛

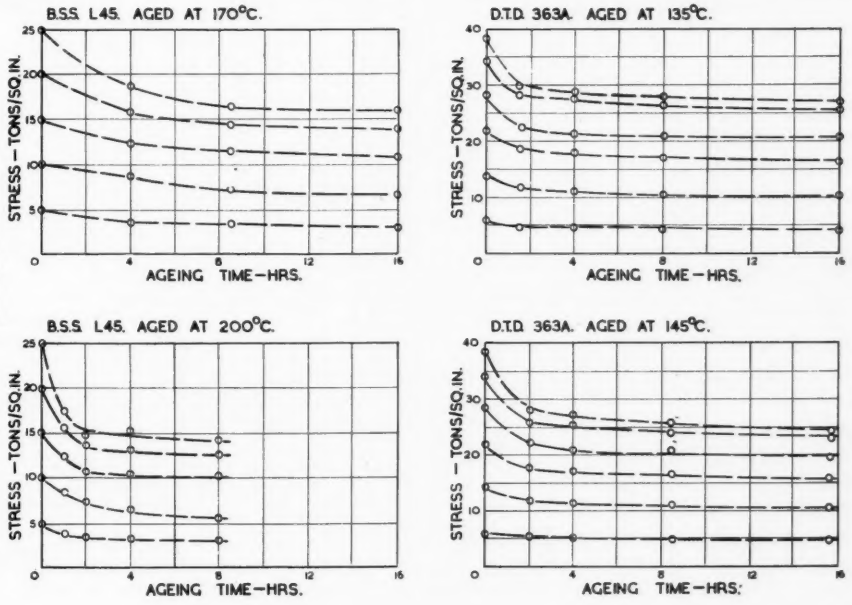


FIGURE 9. Relief of residual stresses during artificial ageing of solution-treated material.

of stress relief, this was accompanied by a drop in mechanical properties and thus was not a satisfactory solution to the problem.

The partial relaxation mentioned above of residual stresses during the artificial ageing process is one of the reasons for the general recommendation that forming operations should be done where possible on the material in the solution-treated state, and should be followed by artificial ageing. A further reason for the recommendation to form in the solution-treated state is that the initial residual stresses will be appreciably lower in this condition than if forming were done after full heat treatment, since the upper limit of residual stress will be subordinate to an appreciably lower proof stress.

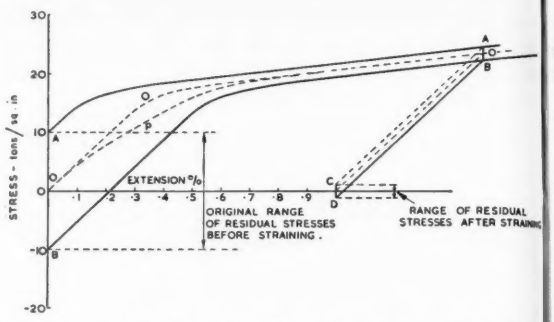

STRESS - tons/sq. in
EXTENSION %
ORIGINAL RANGE OF RESIDUAL STRESSES BEFORE STRAINING.
RANGE OF RESIDUAL STRESSES AFTER STRAINING

FIGURE 10. Reduction of residual stress by tensile straining

3.2. MODIFIED QUENCHING TREATMENTS

A method of minimising residual stresses due to quenching is by the use of modified quenching treatments, usually by quenching in hot water or in oil. In this case the problem becomes one of finding a quenching medium which will result in low residual stress levels and at the same time develop the full mechanical properties of the material.

Table II gives a summary of some investigations on this subject. Three different alloys are concerned and it can be seen that reductions of residual stress of about 70 per cent. can be obtained if a sacrifice of about 10 per cent. in tensile properties can be accepted.

Care is necessary in two respects. First, too literal interpretation of the values tabulated might lead to unexpected results, since the actual behaviour of a given sample of material on quenching will depend on many factors, including its size, and the manner of solution treatment. Should it be required to hot-quench a given part in order to reduce the residual stresses, experimental work should be done as far as possible under production conditions before final conditions of quench temperature are fixed.

The second point in which care must be taken concerns the resistance of materials to corrosion, in that hot-quenching can in many cases result in great reduction of this resistance. Hot quenching is seldom used except for forgings and castings and other such cases where no other satisfactory means for keeping internal stresses at a low level can be devised.

TABLE II

Material	*Quench water*	*Relative residual stress (quench in cold water =100)*	*Tensile Properties*					*Investigator*
			Yield stress tons/in.²	*Yield % of normal yield*	*U.T.S. tons/in.²*	*U.T.S. % of normal U.T.S.*	*Elongation %*	
Avional D	Water 20°C	100	18·3	100	28·2	100	12·4	Zeerleder (1)
	„ 60°C	58	15·6	85	26·6	94	14·4	
	„ 100°C	0	—	—	—	—	—	
	Oil 20°C	30	15·9	87	27·1	96	14·3	
	„ 100°C	25	15·9	87	27·0	96	14·8	
D.T.D.410	Water 20°C	100	23·0	100	26·0	100	1·3	Benson (13)
	„ 70°C	65	21·8	95	25·7	99	1·5	
	„ 85°C	17	20·5	89	24·0	92	1·5	
	„ 100°C	0	16·3	71	21·8	84	3·2	
D.T.D.363A	Water 20°C	100	41·3	100	44·5	100	9	Gunn (15)
	„ 60°C	95	40·9	99	44·5	100	9½	
	„ 70°C	72	39·8	96	43·2	97	11	
	„ 80°C	33	37·6	91	42·1	95	7½	
	„ 90°C	16	32·9	80	38·1	86	10	
	„ 100°C	8	22·8	55	31·6	71	10½	

Avional D — Cu 4%: Si 0·2% Mg 0·6%: Mn 0·5% Fe 0·2%.
—extruded bars of 1·97 in. dia.—H.T. 2 hrs. at 520°C—quenched—aged 24 hrs. at 50°C. Relative stresses are from values of contraction in length on machining off 50 per cent. of cross-sectional area.

D.T.D.410 — Cu 1·8-2·5%: Ni 0·6-1·4%: Mg 0·65-1·2%: Fe 0·6-1·2%: Si 0·55-1·25%: Ti 0·05-0·15%.
—cylinders of dia. 2·437 in. machined from forging—H.T. 2 hrs. at 530°C—quenched—aged 7-8 hrs. at 175°C. Relative stresses are from values of contraction in length on machining off 50 per cent. of cross-sectional area.

D.T.D.363A — Cu 1·5%: Mg 2·2%: Si 0·15% Fe 0·23%: Mn 0·15% Cr 0·10%: Zn 7·5%: Ti 0·045%.
—3 in. square section extrusion. H.T. 3½ hrs. at 460°C—quenched—aged 10 hrs. at 135°C. Relative stress values are from deflection measurements taken after slitting longitudinally.

A large amount of further information on thermal stress-relieving treatments and modified quenching treatments is given in a previous reference[4].

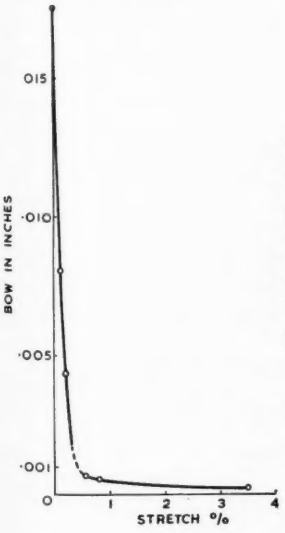
3.3. STRETCHING

The usual method of reducing residual quenching stresses in extrusions of uniform rection, and in sheet, is by stretching. This is generally done in any case to straighten material after heat treatment and quenching. The method by which these stresses are reduced is illustrated in Fig. 10. Suppose that, after quenching, the extruded bar contains a longitudinal stress system varying between ± 10 tons/in.^{2}, in other words, between *A* and *B* of Fig. 10; when the bar is stretched, the stress-strain behaviour of the various elements of the material fall between curves as shown and, assuming that the tensile properties of these elements are all equal, they will all depart from linearity and curve over at the same stress level. Assuming that one per cent. plastic strain is given and the material returns to zero load elastically, the range of stress obtained will only be from *C* to *D*. This is an over-simplification of the matter, since the residual stresses are complex, but the general principle involved will be clear.

For the minimum amount of stretch required to reduce such stresses to low levels, Fig. 11 is of interest. Several lengths of $\frac{1}{2}$ in. $\times \frac{1}{2}$ in. square section were heat-treated and quenched in the normal way. These were stretched various amounts and then slit longitudinally and the resultant bow of the half sections measured. The test results show that, for these sections, the stresses have been reduced to about 10 per cent. of the original by a stretch of 0·5 per cent. (assuming the stresses are proportional to the bow). It is to be expected that, for larger specimens, a somewhat greater quantity of stretch may be necessary.

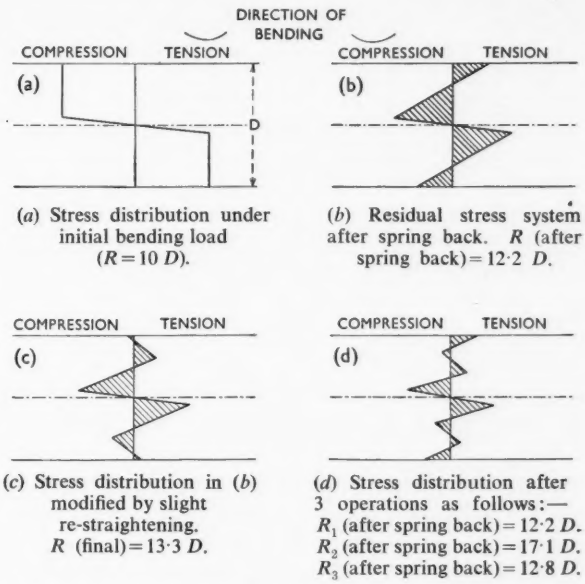
3.4. REVERSE BENDING

A method of controlling residual stresses in bent beams is by slight over-bending and then correction, *i.e.* by reverse bending.



Rectangular section 0·5 in. × 0·6 in. Material Cu 4¼ per cent., Si ¾ per cent., Mn ¾ per cent., Mg ½ per cent. Quenched in cold water from 510° C., aged 6 hours at 170° C., stretched various amounts and machined longitudinally to half the original depth. Bow = deflection at centre of 4 in. length.

FIGURE 11. Relief of quenching stresses by stretching.



(*a*) Stress distribution under initial bending load ($R = 10\ D$).

(*b*) Residual stress system after spring back. *R* (after spring back) = 12·2 *D*.

(*c*) Stress distribution in (*b*) modified by slight re-straightening. *R* (final) = 13·3 *D*.

(*d*) Stress distribution after 3 operations as follows:— R_1 (after spring back) = 12·2 *D*. R_2 (after spring back) = 17·1 *D*. R_3 (after spring back) = 12·8 *D*.

FIGURE 12. Control of residual stresses by reverse bending[17].

The process of development of the stresses in this case is illustrated in Fig. 12. This shows that a small amount of re-straightening will reduce or even reverse the stresses in the extreme fibres, but that a large reduction towards the centre of the beam is not easily obtained. For the drawing of these diagrams, an idealised stress-strain curve has been used which would represent a material with Young's Modulus = 5,000 tons/in.^{2} and a flat yield of 30 tons/in.^{2} (a similar construction has been used previously by Swift[16]).

This process of residual stress control by reverse bending has implications in connection with the flattening of sheet by the use of "roll flattening" equipment. It is probable that, in this process, the residual stresses will be fairly low, at least on the surfaces of the material.

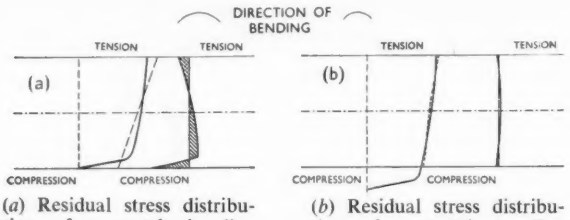
3.5. STRETCH BENDING

Basically, this method involves bending a beam such that all plastic deformation is in tension and by this means it is possible to keep residual stresses to very low values. The mechanism by which this takes place is shown in Fig. 13 which is self-explanatory. The importance of this method of bending, since it virtually eliminates both spring back and residual stress problems, cannot be over-emphasised.

4. Locked Up Stresses—General Comments

Before leaving the subjects of formation and control of residual stresses, it is necessary to mention briefly stresses locked up in structures in general, since self-contained residual stresses in the materials are special cases of the former general category.

Locked-up stresses must exist in any redundant structure in which there is misfit of parts and almost



(*a*) Residual stress distribution after stretch bending with no deformation on extreme lower fibre on bending.

(*b*) Residual stress distribution after stretch bending with neutral axis (on bending) $D/5$ below lowest fibre.

FIGURE 13. Formation of residual stress on stretch bending[17].

inevitably must occur to a greater or less extent in joints —in bolted joints due to the tensile forces developed in the bolts, and sometimes to the use of interference fits; in riveted joints because a well-driven rivet may result in plastic deformation of the plate and heavy permanent radial stresses between rivet and plate; and in welded joints due to non-uniform cooling (and consequent plastic deformation) after the formation of the weld.

In these and in most forms of residual stress systems contained by the materials themselves, there is no general upper limit except the limit imposed by the ability of the materials to yield or relax.

Part II. PRACTICAL SIGNIFICANCE OF RESIDUAL STRESSES

5. Distortion during Machining

Residual stress systems manifest themselves most clearly in the distortion problems which arise when the parts concerned are machined; where unrelieved quenching stresses are concerned this can be very great. The practical difficulties experienced with some extrusions used for aircraft spars during the 1939-45 War provide a good example because they illustrate two types of distortion. The extrusions concerned were approximately 4 in. square in section and approximately 30 ft. long, and on receipt by the user each was slit diagonally along its length to form two tapered spars. On machining a certain batch of these materials, two types of deformation were noted. Firstly, they tended to bow as shown in Fig. 14, so that the centres (on levering out of the milling jig) sprang apart to distances of over 4 ft. and, moreover, each half twisted to an appreciable extent. It was found on investigation of these faults that due to conditions existing in the material manufacturer's works at the time, the normal stretching operation which follows solution treatment had been omitted, straightening being done by other means. When this stretching operation was re-imposed with a minimum limit of $\frac{3}{4}$ per cent. plastic strain, the bow type of deformation disappeared. In connection with the twist which had also been observed after slitting, it was considered that the necessary stresses must have been induced by a de-twisting operation before slitting. Examination was made of a number of extrusions before heat treatment and it was found that all of them had a very slight twist along their length. It had been normal practice to correct this twist after heat treatment and during the stretching operation. By altering the procedure and de-twisting before heat treatment, it was found that the twist did not return after heat treatment and no further trouble arose from this source.

6. Effects on Structural Behaviour Under Static Stress

Experimental work planned to give information on the behaviour of materials containing residual stresses, when externally loaded under static stresses, is complicated by the effects of some additional factors. The first of these is the difficulty of obtaining material initially stress-free to act as a basis of comparison with residually-stressed specimens. Such material must have been either stretched to remove the quenching stresses, quenched in hot water which will have altered the properties in any case, or cut from a very large block of material, when again the properties would be expected to be different.

Another complication is the Bauschinger effect. This has been defined as " A phenomenon by which plastic deformation of a metal raises the yield strength in the direction of the plastic flow and decreases the yield strength in the opposite direction."[17] This means that, if a bar is stretched a small percentage into the plastic range, its yield or proof stress in compression may be reduced and conversely, if it is compressed, its yield in tension may be reduced. This accounts for the fact that compression tests (short test pieces) on some materials give a lower yield than tensile tests. The Bauschinger effect is more noticeable on rolled materials than extruded materials and, where material is artificially aged following plastic deformation, the effect is largely masked.

6.1. EFFECTS ON TENSILE AND COMPRESSION PROPERTIES

The theoretical approach to this problem suggests that a balanced residual stress system in a tension or compression test piece would be expected to lower the limit of proportionality to a considerable extent, but that after appreciable plastic strain has occurred the stress-strain curve from there onwards should be little different from that of an initially stress-free specimen.

The reason for this expectation may be illustrated by further reference to Fig. 10. If the specimen concerned is supposed to consist of two parts of equal cross-sectional area, both having a stress-strain curve defined by the curve *OOO*, but with initial residual stresses of 10 tons tension and 10 compression respectively, on straining, the two parts will follow the curves

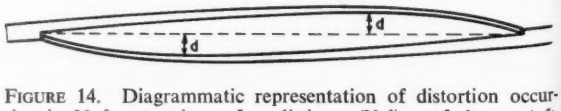


FIGURE 14. Diagrammatic representation of distortion occurring in 30 ft. extrusions after slitting. (Values of d over 4 ft. were obtained.) (DTD.364B solution treated, and quenched in cold water.)

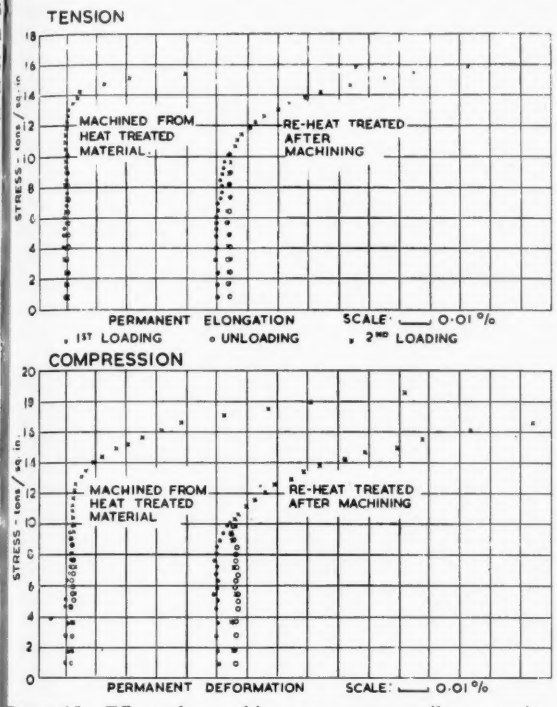


FIGURE 15. Effect of quenching stresses on tensile properties. Material from DTD.150 forging, solution treated at 495° C quenched in cold water.

AA and *AB* respectively, but the stress-strain curve obtained from the specimen as a whole will be *OPO* and not *OOO*, the original stress-strain curve for the material. This illustration concerns longitudinal stresses only.

An experimental investigation[18] on specimens cut from a forged D.T.D. 150 material in which an attempt was made to keep the specimens, stressed and unstressed, as similar as possible, has confirmed that this is the case (*see* Fig. 15), but accurate tests on material to B.S. L45 in which the material was artificially aged after quenching, showed no detectable difference between the residually-stressed and the initially stress-free specimens. This result is open to some doubt, since the bulk of the evidence indicates that artificial ageing reduces the residual stress systems by only 20-40 per cent. Stress-free material was obtained in this case by using material quenched in hot water and by cutting specimens from large blocks. It was not stretched and so the results should not be complicated by the Bauschinger effect. It is not possible to be sure, however, that they had not been affected by other differences between stressed and stress-free specimens.

6.2. EFFECTS ON BENDING

Figure 16[19] illustrates the kind of effect which may be obtained on bent specimens. A rectangular bar of material to B.S. 6L1 was bent as shown in the illustration and the load deformation curve measured. It was then inverted and bent straight again. The load deformation curve obtained on bending straight showed virtually no elastic part and the slope was greatly reduced in the early part of the test. Both the residual stress system resulting from the initial bend, and also the Bauschinger effect due to the initial bend, would tend to reduce the properties on bending in the reverse direction and it is not possible to separate out these two effects.

6.3. COLUMNS

Where high residual stresses exist, they can be expected to reduce buckling loads perhaps appreciably, but only over the range of $1/k$ where buckling is inelastic.

Yang, Beedle and Johnston[20] have dealt with an unsupported plate under edge compression containing a symmetrical parabolic residual stress system (*see* Fig. 17), the outer edges of the plate being in compression and the maximum value of residual stress being one half the yield stress. They assume an idealised stress-strain curve for the material (*i.e.* two straight lines with moduli E and zero) and calculate the column strength for the cases of flexure both about minor and major axes of the plate using the tangent modulus concept for buckling. Their plotted curves show that for the most critical value of $1/k$ a loss of strength could amount to 22 per cent. for flexure about the weak axis, or to about 32 per cent. for flexure about the strong axis. (This variation of effect with direction of flexure is only related to the direction of the strong and weak axes insofar as they, in turn, are related to the plane of the residual stress distribution.)

Yang, Beedle and Johnston have not dealt with non-symmetrical residual stress distributions.

6.4. STRUCTURAL PARTS IN TENSION

In this connection residual stresses are probably of most importance where joints exist and where any deformation which takes place is limited to points of stress concentrations with effectively very small gauge lengths.

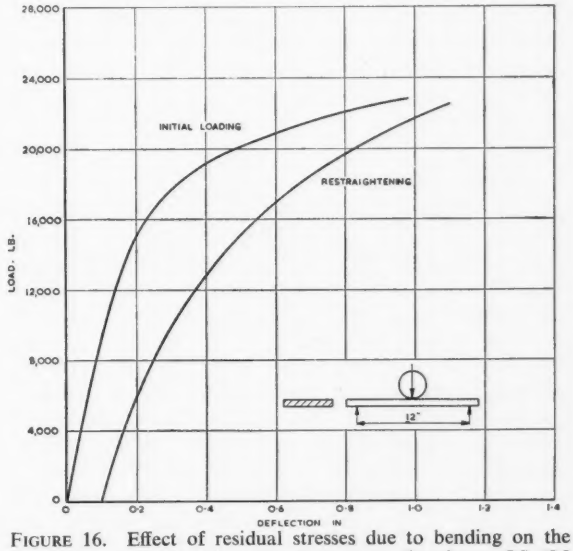
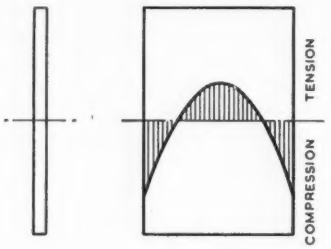
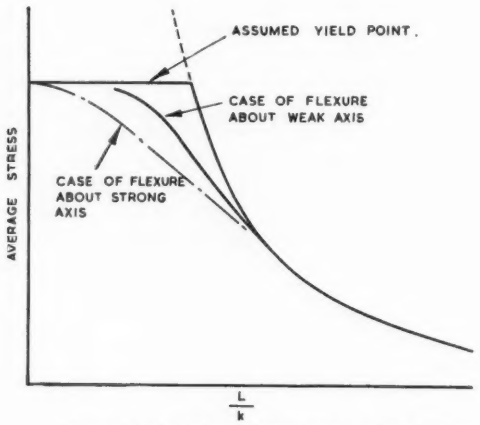


FIGURE 16. Effect of residual stresses due to bending on the properties of material bent in the reverse direction. (BS 6L1 rectangular section $\frac{7}{8}$ in. x 5 in.[28])



Residual stress distribution in plate.



Stress/strain diagram idealised to consist of two straight lines with slopes E and zero.

FIGURE 17. Effect of residual stresses on column strength. (Maximum value of residual stress in compression = $\frac{1}{2}$ yield strength of material.) (Yang, Beedle and Johnson[29].)

This means that extremely small deformations at joints will not produce appreciable deformations of the structure as a whole and in fact the first heavy loading will probably produce sufficient plastic deformation partially to relieve such stresses, so that the structure will behave elastically up to such loads under subsequent loading. This latter point is very important, since under many forms of loading a small amount of plastic deformation will effectively produce a recovery of elasticity and, in general, the deformations necessary will be small.

7. Stress Corrosion

The effects of residual stresses on stress corrosion should presumably be considered under the heading Static Stresses, although the type of failure is brittle and in some ways more closely parallel to fatigue failure. There is only one logical course of action which can be taken at present and this is to assume that residual stresses will have the same effect on the corrosion problem as externally applied stresses. This assumption should be on the safe side, since with any structure in service the actual service will tend to reduce residual tensile stresses (except where service loads are in compression) and cannot possibly increase them. In considering this problem, which must concern the manufacturer of material as much as, or more than, the user, the manufacturer must realise that it is not enough for his materials to behave adequately at stress levels such as are normally recommended as working stresses; he has to realise that a structure may have very much higher stresses than these, stresses which may only be limited by the yield stress of the material.

8. Behaviour under Fatigue Stress

This is an aspect of service conditions in which residual stresses may be expected to have large effects, either good or bad. As a first approximation, it would be reasonable to suppose that a residual stress can be treated in the same way as an externally applied stress, in other words, as an additional mean stress superimposed on the fatigue cycles. The complication may be expected that at high cyclic stress levels the residual stress systems may be modified. Little work has been done on this point, *i.e.* the modification of residual stress systems by cyclic stresses for aluminium alloys. The problem would be a very complicated one, since modification of a residual stress system would inevitably depend not only on the cyclic stresses and the initial magnitude of the residual stresses, but also on the size and shape of the test piece and the stress gradients involved.

Work on residually stressed specimens to show the order of effect which may be expected under certain specific conditions may be usefully described here.

8.1. EFFECTS OF QUENCHING STRESSES

The first series of experiments[21] were on the effects of quenching stresses on rotating cantilever test pieces of the forms shown in Fig. 18. Tests were made on test pieces cut from large forged blocks quenched in hot water to give virtually "stress-free" test pieces and also on test pieces which were fully re-heat treated after complete machining and, for the notched test pieces, after machining to size, with the notch machined after the re-heat treatment. Two materials were used, a naturally aged material corresponding to D.T.D. 150 and an artificially aged material corresponding to B.S. L45. The results are also shown in Fig. 18, from which it may be seen that little alteration of behaviour was obtained on the notch-free specimens, but where notches existed an improvement in fatigue properties of up to 80 per cent. (in terms of stress) had been obtained. It will be remembered that residual stresses due to the quenching of cylindrical shapes are heavily compressive on the outside. This large improvement must be related not only to the residual stress system, but to the specific shape of the specimen, the type of notch and also, the method of stressing (*i.e.* rotating bar as against axial load tests) and it would not be safe to assume that a test piece of any other shape would show the same quantitative effect.

8.2. EFFECTS OF SINKING PASS IN TUBE

The next series of tests concerned residual stresses which resulted from the "sinking" of a tube, since it was realised that a sinking pass would give a residual tension on the outside as opposed to the heavy compression which results from quenching. In this case only notched

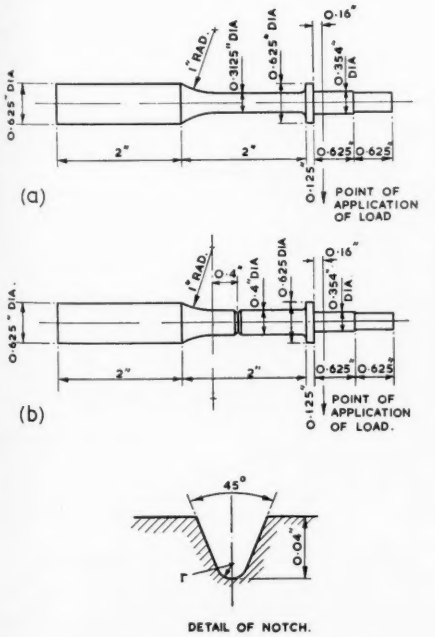
test pieces as shown in Fig. 19 were used. Tests were made on the tube in various conditions as shown in the diagram and (referring to the diagram), if sample *D* is considered as virtually stress-free material, it can be seen that the sunk tube has a strength of less than two-thirds the normal value.

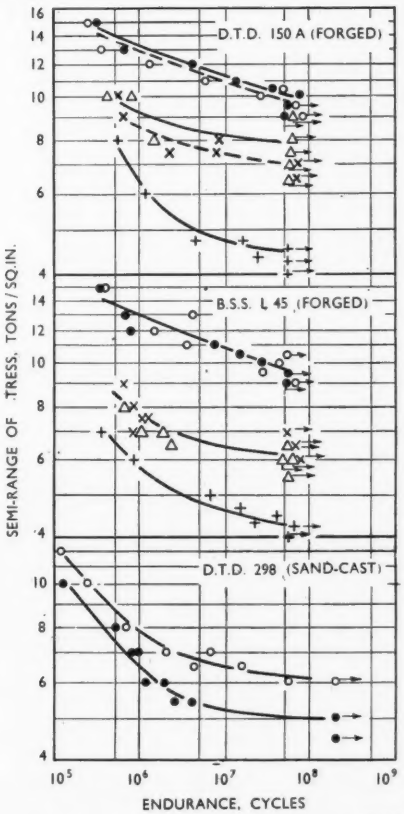
8.3. EFFECTS OF PRE-LOADING

The effects of tensile pre-loading of samples of material with stress concentrations in inducing compressive residual stresses round the discontinuity have previously been described. Fig. 20 shows fatigue tests on rotating cantilever specimens containing annular notches, some of which were pre-loaded in tension to nominal stresses (on the area at the root of the notch) of three-quarters of the ultimate tensile stress. These show that a very great improvement may result from pre-loading such that the root of the notch is subjected to a residual compression.

The conditions for these tests were chosen such that any effect the pre-loading had on the fatigue behaviour was likely to show up distinctly and the results cannot be quantitatively applied to other forms of notch.

Some interesting tests have been made by Rosenthal and Sines[22] in which an attempt was made to consider the effects of such stresses quantitatively. The work was done on notched test pieces of a design shown in Fig. 21. Fatigue stressing was done under both reversed and repeated flexure, and X-ray, measurements were made to determine the residual stresses at the roots of the notches. The residual stresses—both compressive and tensile—were applied by pre-loading the specimens under tension and compression respectively, as has been described already. The material used was an aluminium magnesium-silicide medium strength alloy, giving in its fully heat-treated state a stress-strain curve similar to that of the high strength artificially aged alloys, but a lower stress level—essentially, the ratio of yield to ultimate strength is high (nearly 0·9). Tests were made on the material after full heat treatment, to give conditions under which it was considered that the residual stresses would persist to the greatest possible extent during actual fatigue tests, and also in the annealed condition which would be at the opposite extreme, *i.e.* the maximum relief would occur under fatigue stressing. Fig. 21 shows the results of some of Rosenthal's and Sines' tests and it can be seen that the results confirm qualitatively the tests on the "annular notched specimens" already quoted, but show that with less complex stress conditions at the root of their notch the





CHEMICAL ANALYSIS

	DTD. 150	BS. L45	DTD. 298
Cu%	4·15	3·51	4·13
Fe%	0·48	0·63	0·18
Mn%	0·57	0·63	0·001
Mg%	0·52	0·40	—
Si%	0·46	0·83	0·25

TENSILE PROPERTIES
(as received)

	DTD. 150	BSS. L45
0·1% Proof Stress, tons/in.²	14·8	25·1
Ultimate Tensile Stress, tons/in.²	27·5	30·4
Elongation %	21	13½

DTD.298 hardness $H_{D/20} = 90$

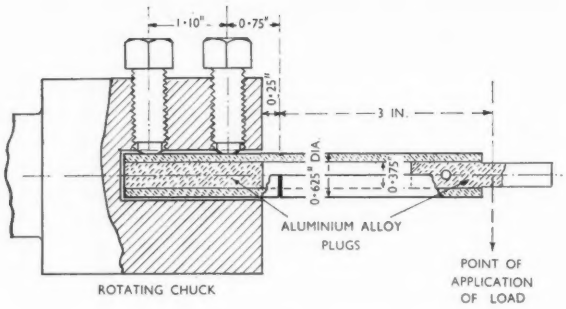
Polished specimens.

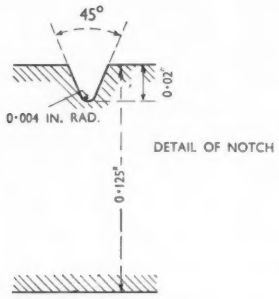
● Machined from heat-treated materials (low residual stresses)
○ Heat-treated after machining (high residual stresses)

Notched specimens.

\+ Machined from heat-treated material (low residual stresses)
△ Heat-treated after machining (high residual stresses)
× Heat-treated after machining to size but before cutting notch

FIGURE 18. Effect of quenching stresses on fatigue properties[12]



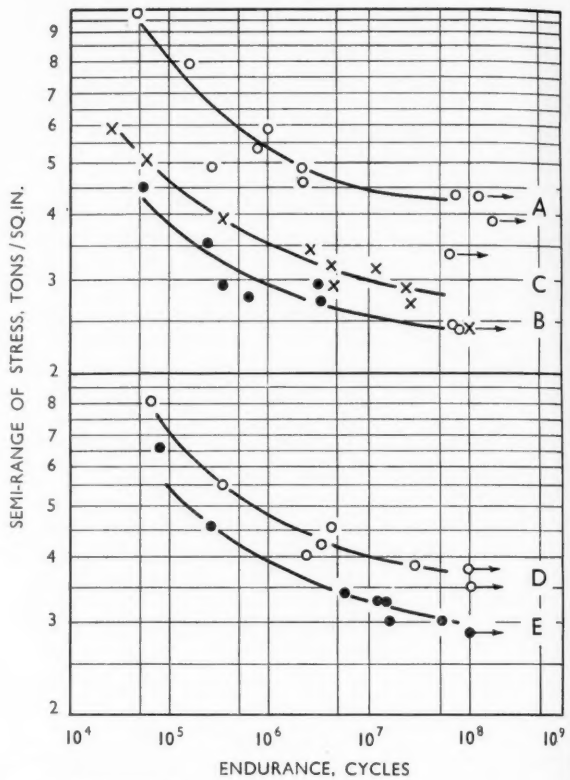


CHEMICAL ANALYSIS

	Cu	Fe	Mn	Mg	Si
	%	%	%	%	%
BS. 5T4	4·33	0·39	0·66	0·58	0·67

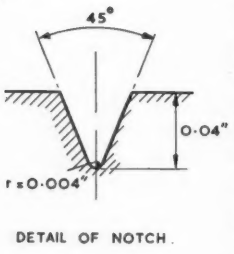
TENSILE PROPERTIES

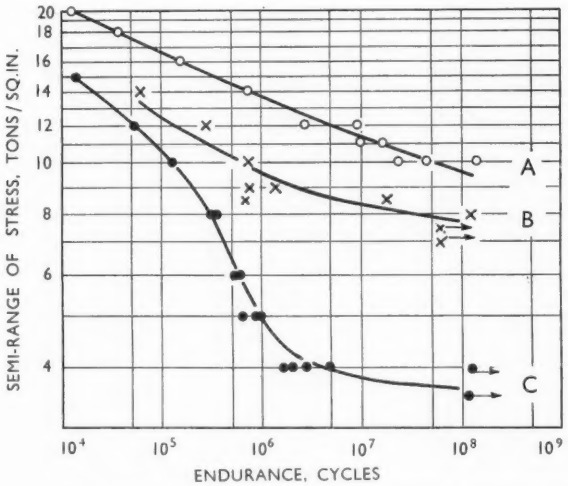
	0·2 % Proof Stress tons/in.²	Ultimate Tensile Stress tons/in.²	Elongation %
A	18·0	30·8	29
B	21·6	32·3	15
C	25·9	32·0	14



A As heat-treated.
B As heat-treated and sunk.
C As heat-treated, sunk, stretched about ½ per cent. and reeled.
D As heat-treated and stretched 2 per cent.
E As heat-treated, sunk and stretched 2 per cent.

FIGURE 19. Effect of sinking on the fatigue properties of a tube[12].





A Polished test-pieces.
B Notched test-pieces, pre-loaded.
C Notched test-pieces.

CHEMICAL ANALYSIS

	Cu	Fe	Mn	Mg	Si
	%	%	%	%	%
BS.6L1	4·15	0·53	0·61	0·51	0·53

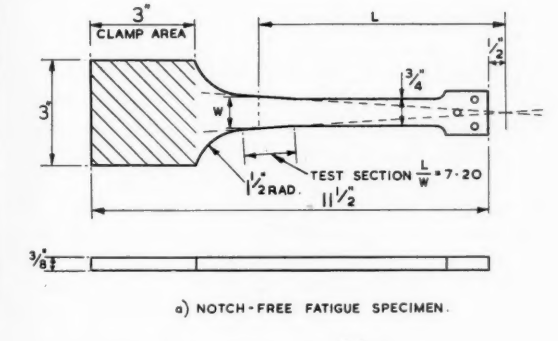
TENSILE PROPERTIES

0·1% Proof Stress tons/in.²	Ultimate Tensile Stress tons/in.²	Elongation %
17·9	30·1	16

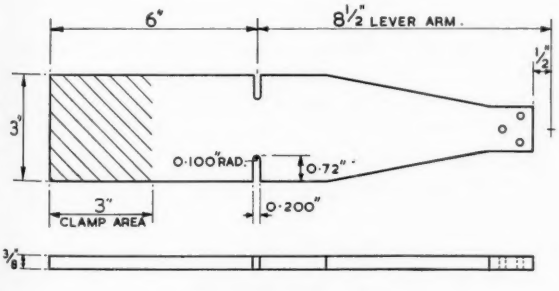
FIGURE 20. Effect of pre-loading on fatigue of notched test piece[12].

improvement due to pre-loading in tension has been very much less than was shown with annular notches. The test results on the annealed material are not reproduced, since in this case the residual stresses have had no obvious effect. The explanation is to be found in Rosenthal's and Sines' X-ray stress measurements taken after a number of fatigue cycles have been endured. With the soft material the fatigue cycles either reduced the residual stresses to very small values (under reversed bending) or, with pulsating bending, they induced residual stresses in the initially stress-free specimens, nearly equivalent to the stresses produced by the deliberate pre-loading operation.

In the discussion to Rosenthal's and Sines' paper, R. L. Templin[23] has described rotating beam tests on notch test pieces roughly similar to those described by the present author, but using the aluminium-zinc-magnesium alloy 75S-T6 and using specimens pre-loaded in compression as well as tension. These test pieces were also pre-loaded at nominal stresses which would be expected to cause an appreciable yield at the roots of the notches. The notches in this case were of depth 0·075 in. with a notch of 60° included angle and of sharp root radius (less than 0·002 in.). The test results showed that the increase of fatigue strength strength at 10 million cycles resulting from compression stresses at the notch roots (*i.e.* pre-loaded in tension) was 75 per cent. and the decrease with specimens containing residual stresses in tension (with pre-load in compression) was 67 per cent. of the strength of the initial " unstressed " specimens.

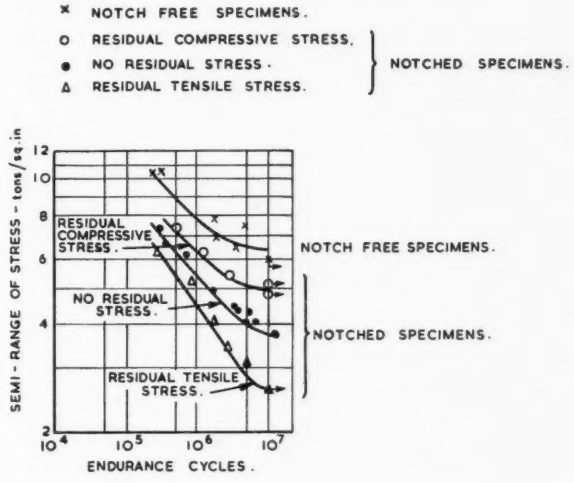


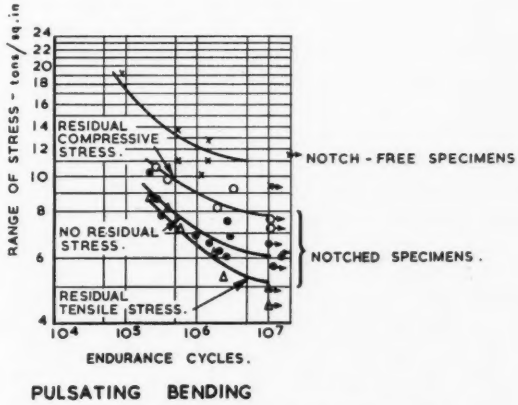
a) NOTCH-FREE FATIGUE SPECIMEN.



b) NOTCHED FATIGUE SPECIMEN.

FATIGUE SPECIMENS





CHEMICAL ANALYSIS

Cu	Cr	Si	Mg
%	%	%	%
0·25	0·25	0·6	1·0

TENSILE PROPERTIES

0·2% Proof Stress tons/in.²	Ultimate Tensile Stress tons/in.²	Elongation %
17·9	20·1	12

FIGURE 21. Effect of residual stresses on notched test pieces. (Rosenthal and Sines[30].)

These test results demonstrate conclusively that residual stress systems arising from either heat treatment or mechanical manipulations may have extremely large effects on fatigue behaviour which may be either good or bad.

8.4. PRE-LOADED SPOT WELDED JOINTS

To obtain information under some practical conditions a series of tests was made on spot welds[21]. The test pieces consisted of simple lap joints in 20 gauge clad sheet to D.T.D. 546A. Fatigue tests were made on specimens containing single spot welds under shear load conditions described by $P(1 \pm \frac{1}{2})$, *i.e.* with a mean stress equal to the range of stress in the case of each separate test. Some of the spot weld test pieces were tested with no treatment following spot welding and further tests were made on similar test pieces after loading under static tension with loads equal to two-thirds of the average static strength of the joints; an increase of fatigue properties was obtained in this case of 50 per cent. (*see* Fig. 22). Since it can be supposed that a spot weld as normally manufactured is heavily loaded with residual stresses, some at least of which will be in directions tending to lower the strength, it must be assumed that the improvement may be due partly to the removal of some of these stresses and partly to the induction of a further system of stresses in advantageous directions.

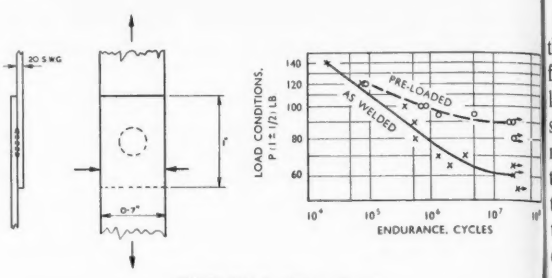
8.5. PRE-LOADED RIVETED JOINTS

Recently a similar preliminary series of tests has been made on riveted joints. In this case no advantage from pre-loading was obtained. This may be due to the fact that a well-made riveted joint is already loaded with high compression stresses between the rivet and the hole and the pre-loading may merely have loosened the rivets. Alternatively failure may have been due to some other cause, such as frettage corrosion under the rivet heads or at the sheet interface—a possibility in some degree supported by the fact that several failures occurred at parts of the sheet away from the rivet holes.

8.6. SURFACING STRESSING

Many other methods of applying residual stresses have been considered, among which can be included shot peening and surface rolling and also, the pre-loading of rivet holes. None of these methods has come into general use with light alloys, although there are a number of special cases such as, for example, the surface rolling of the hubs of propeller blades first reported by Sachs (on magnesium alloys)[24], and the shot blasting of the internal cavity in the hub of certain aluminium alloy propellers for the purpose of avoiding "stress cracking"[4].

It is not possible here to afford even an adequate summary of the very large number of investigations that have been made on the effects of shot peening, but a few results by Gleason[25] might be of interest. Gleason tested specimens from forged slabs of 14ST (an American material similar to D.T.D. 364B) under reversed flexure and found that, with unnotched specimens, the number



DTD.546A. 20g. sheet.
Pre-load = $\frac{2}{3}$ static strength.

FIGURE 22. Effect on fatigue of pre-loading spot welds[12].

of cycles to failure at specific stresses above the endurance limit could be increased by shot peening under optimum conditions to 80 times that of unpeened test pieces. With notched specimens (containing a $\frac{1}{16}$ in. radius and depth of groove, and root diameter of test pieces of $\frac{1}{4}$ in.) an increase of stress range was obtained of more than 32 per cent., corresponding to a hundred million cycles.

8.7. LOCKED UP STRESSES DUE TO INTERFERENCE FITS

Although locked up stresses due to the use of interference fits are not strictly residual stresses in the sense used in this survey, mention of some recent very valuable test results obtained by Fisher[26] is necessary. The tests were made on "loaded hole" specimens in which the material was a high strength aluminium alloy and the loading was carried out through mild steel bushes inserted in the holes with various degrees of interference. Further tests were made in which bushes were not used and the steel pins themselves were fitted with various degrees of interference.

With suitable degrees of interference an increase of life of the order of x 50 was obtained. Since the majority of the relevant "interference" specimens were unbroken at the conclusions of Fisher's tests, it is possible that vastly greater improvements may be obtained than the foregoing figures indicate.

9. General Discussion

It has been shown that, although in some forms aluminium alloys do reach the producer in a relatively stress-free condition and, in fact, nearly all extruded and rolled materials do so, it is unwise to rely upon it. Moreover, when such materials have been manipulated by the user and built into structures, the chances of their being left in a stress-free state are somewhat remote. In general the residual stresses may have any value even up to the yield; except that, when these stresses have been induced before the final heat treatment, the maximum stresses are limited to values less than the yield of the material before full heat treatment and thus should be considerably below the yield stress in the finished state.

It has also been shown that the effects of such stresses on the static behaviour of a structure will in general be small, but effects on fatigue behaviour may be marked.

Where fatigue failure occurs in service, it is certain that the "locked up" stresses at the point of failure will frequently be major factors in determining the length of life before failure; in particular if these stresses can be so controlled that they act in specific directions, they may be of great value in improving fatigue strength. In this connection it may often be possible to take advantage of the observation that a single static overload in the direction of the service stresses appears to remove disadvantageous residual stresses and to induce advantageous ones, and so to improve fatigue behaviour. It is of interest that Tye[27] has recently reported that ". . . if new components are tested they sometimes give a lower average life than would be indicated by the tests on specimens withdrawn from service." Tye ascribes this phenomenon to the occasional high load experienced in service which may have the same effect as pre-loading before test, and suggests that it can be explained on the basis that the component is "settled down" by the pre-load. This is apparently half of the explanation, since "settled down" consists partially at least of ironing out stress peaks (residual and otherwise), *i.e.* the removal of unwanted stresses. The other half may well be the induction of advantageous stresses which in themselves increase the basic fatigue properties of the component.

Wills[28] has quoted the results of tests on several Mustang wings which were subjected to a static load of the order of 80 per cent. of the ultimate failing load before undergoing fatigue tests. He states that these tests have shown that appreciable increase in endurance can be obtained by this means.

Teed[29] has recently suggested making use of this phenomenon by pre-loading aircraft, before putting them in service, by the application of a single heavy overload in actual flight.

The suggestion of pre-loading complete structures is open to many criticisms, particularly since it pre-supposes that the structure is only loaded in service in one direction. A more practical approach is suggested by Fisher's work, *i.e.* the close control of joint design and assembly methods such that compressive stresses may be deliberately built into the structures at the critical points.

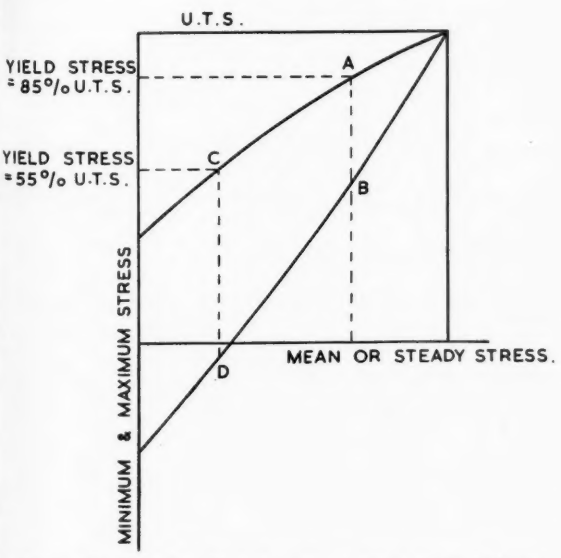


FIGURE 23. Relationship of range of stress under fatigue, to mean stress.

9.1. IMPLICATION REGARDING CHOICE OF MATERIALS

Figure 23 represents a Goodman Diagram relating mean stress to fatigue range. Now if two materials are available with equal static tensile and fatigue characteristics (as found by normal laboratory tests), except that the yield of one material is much lower than the other, and if uncontrolled unfavourable residual stresses limited only by the respective yield stresses are assumed, then, whatever the externally applied loads, the material with a high yield (say 90 per cent. U.T.S.) will have less "fatigue resistance" than the material with a low yield (say 60 per cent. U.T.S.). Referring to the diagram, the two materials would be expected to give fatigue properties corresponding to *AB* and *CD* respectively. This means that, in a complicated structure designed to resist fatigue and ignoring static strength considerations, the "low yield" structure should be appreciably the stronger.

A further advantage of the low yield material is that stress redistribution will occur at much lower stresses and if over-loading, or the use of interference fits at joints, do, on further investigation, prove to be of general value, the redistribution will occur either at less overload, or will be more widely distributed with equally heavy loads.

This means that it would be better to use a material of low ratio of yield to ultimate stress, where fatigue is likely to be the cause of failure. There is, in fact, considerable evidence that such material (low yield) in the form of joints or with other forms of stress concentration gives the better fatigue properties over certain ranges of endurance. The disadvantage of using a low yield material is that an increase in structural weight becomes necessary owing to static load considerations.

The problem therefore becomes one of getting the best of both worlds and it is possible that this may be achieved by rigid control of residual and locked-up stress systems, such that they are always favourable at critical points in the structure. It has been stated that stress peaks may be modified, and residual (or locked-up) compression stresses induced, at lower stresses in the low yield materials. Assuming, however, that by suitable pre-loading processes, compressive residual stress systems can satisfactorily be induced in both classes of material (*i.e.* low and high yield) these stresses will be higher in the high yield materials. It is not known yet whether there is an upper limit to such compression stresses beyond which the superimposed fatigue range is reduced, or if on the other hand continued increase to the highest possible values results in improvement. If the latter is the case, it may be that, by suitable manipulation of residual and locked-up stress systems, the high yield material may prove the better under fatigue as well as under static stress conditions.

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WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

Eighty-Ninth Annual Report of the Council 1953-1954

1953 HAS BEEN AN OUTSTANDING YEAR in the history of the Society; it was the year in which was celebrated the 50th Anniversary of the First Powered Controlled Flights by the Wright Brothers and a year in which the Fourth Anglo-American Aeronautical Conference was held in London.

To mark the 50th Anniversary a Dinner was held at The Dorchester on 17th December 1953, and the Garden Party was given an historical flavour. In addition a special issue of the JOURNAL was published in December.

Although these special occasions have inevitably meant more work for the Office Bearers and Staff of the Society, there has been no curtailment in the normal Society activities. In fact, a close examination will show that the number of Section Lectures has been increased.

To enable the Report to cover in future the Council Year, not the Calendar, this present Report relates the activities of the Society for the fifteen months from January 1953 to March 1954.

The Council for the year 1953-1954 was as follows :-

PRESIDENT

SIR WILLIAM S. FARREN, C.B., M.B.E., M.A., F.R.S., HON.F.I.A.S., F.R.AE.S.

PAST PRESIDENTS

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MAJOR G. P. BULMAN, C.B.E., B.SC., F.R.AE.S.

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PROFESSOR A. R. COLLAR, M.A., D.SC., F.R.AE.S.
E. B. DOVE, A.R.AE.S.
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N. J. HANCOCK, A.F.R.AE.S.
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W. E. W. PETTER, C.B.E., B.A., F.R.AE.S.
CAPTAIN J. LAURENCE PRITCHARD, C.B.E., HON.F.I.A.S., HON.F.R.AE.S.
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J. G. ROXBURGH, A.F.R.AE.S.
B. S. SHENSTONE, M.A.SC., F.R.AE.S.
W. TYE, O.B.E., B.SC., F.R.AE.S.
C. F. UWINS, O.B.E., A.F.C., F.R.AE.S.

OFFICERS

Honorary Treasurer: C. F. UWINS, O.B.E., A.F.C., F.R.AE.S. (*to January* 1954)
MAJOR G. P. BULMAN, C.B.E., B.SC., F.R.AE.S. (*from February* 1954)

Solicitor: L. A. WINGFIELD, M.C., D.F.C., A.R.AE.S.
Secretary: DR. A. M. BALLANTYNE, T.D., A.F.R.AE.S.

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SIR SYDNEY CAMM, F.R.AE.S. (*Vice-President* and *President-Elect*)
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*H. H. GARDNER, F.R.AE.S.
*M. B. MORGAN, F.R.AE.S.
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J. G. ROXBURGH, A.F.R.AE.S.
*A. E. RUSSELL, F.R.AE.S.

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PROFESSOR A. D. BAXTER, F.R.AE.S.
*L. BRIDGMAN, A.R.AE.S.
*C. G. BURGE, A.R.AE.S.
G. H. DOWTY, F.R.AE.S.
SIR HARRY GARNER, F.R.AE.S.
*MAJOR R. H. MAYO, F.R.AE.S.

MEDALS AND AWARDS COMMITTEE

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A. G. ELLIOTT, F.R.AE.S.
E. T. JONES, F.R.AE.S.
W. E. W. PETTER, F.R.AE.S.
N. E. ROWE, F.R.AE.S.
*SIR HAROLD ROXBEE COX, F.R.AE.S.
W. TYE, F.R.AE.S.
*PROFESSOR W. A. MAIR, A.F.R.AE.S.

BRANCHES COMMITTEE

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*E. M. BELLAMY, A.R.AE.S.
*A. V. CLEAVER, F.R.AE.S.
*A. C. CLINTON, F.R.AE.S.
*J. G. DAWSON, A.F.R.AE.S.
N. J. HANCOCK, A.F.R.AE.S.
*E. J. MANN, A.R.AE.S.
*E. L. PEARSON, A.R.AE.S.
*PROFESSOR E. J. RICHARDS, F.R.AE.S.
*J. H. SINCLAIR, A.F.R.AE.S.
*DR. E. W. STILL, F.R.AE.S.

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A. A. HALL, F.R.AE.S.
*M. LANGLEY, F.R.AE.S.
*GROUP CAPTAIN W. G. MATTHEWS
DR. E. S. MOULT, F.R.AE.S.
*E. F. RELF, F.R.AE.S.

GRADUATES' AND STUDENTS' COMMITTEE

J. G. ROXBURGH, A.F.R.AE.S. (*Chairman*)
*J. D. ARTHUR, *Graduate*
*G. E. D. BONHAM CARTER, *Student* (Resigned November 1953)
*A. E. BROCK, *Graduate*
*M. C. CAMPION, *Graduate*
*E. J. CATCHPOLE, *Graduate*
E. B. DOVE, A.R.AE.S.
*J. C. HALL, *Student*
N. J. HANCOCK, A.F.R.AE.S.
*H. S. METTAM, *Graduate*
*C. B. REDGATE, *Graduate*
*D. J. W. RICHARDS, *Student*

**Not Members of Council.*

Representatives on Other Bodies

General Board of the National Physical Laboratory: Sir William Farren and Major G. P. Bulman.

Executive Board of the National Physical Laboratory: Sir Arthur Gouge.

Royal Society—National Committee for Theoretical and Applied Mechanics: Mr. A. A. Hall.

Institution of Electrical Engineers—Committee on Regulations for the Electrical Equipment of Aircraft: Mr. C. G. A. Woodford.

Institution of Electrical Engineers—Committee on Radio Equipment for Civil Aircraft: Mr. C. H. Jackson.

Institution of Mechanical Engineers—National Certificates and Diplomas in Mechanical Engineering: Mr. R. Tatham.

Engineering Joint Council: Major F. B. Halford.

Engineering Joint Council—Special Education Representative: Professor G. T. R. Hill.

Governing Body of Institute of Technology, Loughborough: Mr. A. G. Elliott.

Board of Governors of the R.A.E. Technical College: Sir William S. Farren and Professor A. R. Collar.

College of Aeronautics Board of Governors: Sir Roy Fedden and Sir Harold Roxbee Cox.

British Standards Institution—Nomenclature Committee: Dr. D. M. A. Leggett.

British Standards Institution—Units and Symbols Standards Committee: Dr. A. M. Ballantyne and Miss E. C. Pike.

British Standards Institution—Aircraft Industry Standards Committee: Mr. H. Knowler and Mr. F. M. Owner.

British Standards Institution—Jewels and Pivots for Instruments Committee: Major B. W. Shilson.

British Standards Institution—Technical Committee USM/1: Sir Sydney Camm.

Segrave Trophy Committee: Major R. H. Mayo.

City and Guilds of London Institute—Advisory Committee on Aeronautical Engineering Practice: Sir Roy Fedden, Mr. R. L. Lickley, Mr. B. S. Shenstone and Dr. A. M. Ballantyne.

City and Guilds of London Institute—Education Policy Committee: Sir Arthur Gouge.

Association of Special Libraries and Information Bureaux: Captain J. L. Pritchard.

National Central Library: Captain J. L. Pritchard.

Regional Advisory Committee for Mechanical Engineering: Sir John S. Buchanan.

University of London—Facu'ty of Engineering Special Committee: Mr. R. S. Stafford.

University of London Senate—Board of Studies: Dr. A. M. Ballantyne.

Court of University of Bristol: Dr. A. E. Russell.

Royal Technical College, Salford—Engineering Advisory Committee: Mr. S. D. Davies.

Election of President and Vice-Presidents

Sir William Farren, C.B., M.B.E., M.A., F.R.S., Hon.F.I.A.S., F.R.Ae.S., was elected President for 1953/54 and took office at the Eighty-Eighth Annual General Meeting held on 7th May, 1953.

At the Meeting of Council held on 21st May 1953 the following were elected Vice-Presidents:

Sir Sydney Camm, C.B.E., F.R.Ae.S.
G. R. Edwards, C.B.E., B.Sc., F.R.Ae.S.
P. G. Masefield, M.A., F.I.A.S., F.R.Ae.S.

At the Meeting of Council held on 25th June 1953 Sir Sydney Camm was elected President-Elect.

Fellowship of the Society

At the Eighty-Eighth Annual General Meeting, held on 7th May 1953, the following were elected Fellows:

L. Boddington
M. J. Brennan
E. E. Chatterton
J. M. Gray
C. N. Jaques
A. A. Lombard
B. K. O. Lundberg
W. R. McGaw
H. Pearson
H. Povey
B. E. Stephenson
H. Templeton
H. J. van der Maas

Lectures

The following are the Main Lectures and Section Lectures read before the Society in 1953/54:—

29th January: MAIN LECTURE—Titanium—A Survey, by Major P. L. Teed.

12th February 1953: SECTION LECTURE—The Application of Integral Construction and its Effect on Production Methods, by E. Dixie Keen.

17th February: SECTION LECTURE—Recent Developments in Gliding, by A. H. Yates.

26th February: MAIN LECTURE—New Materials and Methods for Aircraft Structures, by H. J. Pollard.

12th March: MAIN LECTURE—Some Aspects of High Performance Jet Aircraft, by W. A. Waterton. (At Derby.)

19th March: MAIN LECTURE—Sixth Louis Bleriot Lecture: Making Commercial Aircraft Pay, by General Guy du Merle. (July 1953 JOURNAL.)

27th March: Full Day Discussion on Fatigue. (September 1953 JOURNAL.)

23rd April: MAIN LECTURE—Civil Jet Operations, by Captain A. M. A. Majendie. (At Glasgow.)

21st May: Aeronautical Acoustics (All Day Joint Meeting with Acoustics Group of the Physical Society on Aeronautical Acoustics—In Particular Jet Noise). (April 1954 JOURNAL.)

11th June: MAIN LECTURE—Ninth British Commonwealth and Empire Lecture—Some Problems in the Development of Air Transport in West Africa, by Sir Hubert Walker. (August 1953 JOURNAL.)

14th September 1953: MAIN LECTURE—41st Wilbur Wright Memorial Lecture, Structures—Buckling

and Stability, by Professor N. J. Hoff. (January 1954 JOURNAL.)

13th October: SECTION LECTURE—The Use of Materials in the Plastic Range, by H. L. Cox.

29th October: MAIN LECTURE—A Quantitative Study of Instrument Approach, by J. F. W. Mercer.

3rd November: SECTION LECTURE—The Development of 4,000 lb. per sq. in. Hydraulic Systems, by G. Orloff.

10th November: SECTION LECTURE—Gusts and Their Measurement, by J. Taylor.

12th November: MAIN LECTURE—Stability and Control in Aircraft Design, by J. C. Wimpenny.

19th November: SECTION LECTURE—Aircraft Stability and Control, by A. W. Babister.

1st December: SECTION LECTURE—Integral Construction, by K. L. C. Legg.

10th December: MAIN LECTURE—Flight Simulators, by C. B. Ringham and Dr. A. E. Cutler. (At Belfast.)

15th December: SECTION LECTURE—Jet-Driven High-Speed Wind Tunnels, by D. L. Ellis.

7th January 1954: MAIN LECTURE—Lecture to Young People: The Fun of Finding Out in Flying, by Sir Leonard Bairstow.

21st January: MAIN LECTURE—First Mitchell Memorial Lecture, by J. Smith. (At Southampton.)

26th January: SECTION LECTURE—X-Ray Metallography, by Dr. G. L. J. Bailey.

4th February: SECTION LECTURE—Air Intake Efficiency, by F. B. Greatrex.

11th February: MAIN LECTURE—Recent Developments in the Structural Approach to Aeroelastic Problems, by Dr. D. Williams.

18th February: SECTION LECTURE—Helicopter Research (Joint Lecture with the Helicopter Association), by F. J. O'Hara.

2nd March: SECTION LECTURE—Metal Sandwich Construction, by F. Tyson.

4th March: MAIN LECTURE—First Barnwell Memorial Lecture, by Major G. P. Bulman. (At Bristol.)

10th March: MAIN LECTURE (PARIS)—The 7th Louis Bleriot Lecture: The Domain of the Helicopter, by R. Hafner.

16th March: SECTION LECTURE—The Development of the Spill Flow Burner and its Control System for Gas Turbine Engines, by F. H. Carey.

30th March: SECTION LECTURE—Interaction between Shock Waves and Boundary Layers and its importance in High-Speed Flight, by Dr. D. W. Holder.

The following lectures complete the programme:—

6th April: SECTION LECTURE—A Review, from the Design Aspect, of Materials used in Rocket Motors, by G. O. Jones.

8th April: MAIN LECTURE—Practical Experience of Airline Engineering, by R. C. Morgan. (At Chester.)

13th April: SECTION LECTURE—Some Aspects of Modern Aircraft Materials, by Dr. H. Sutton.

22nd April: MAIN LECTURE—Diesel Compound Engines, by E. E. Chatterton.

27th April: SECTION LECTURE—Aerodynamic and Aeroelastic Characteristics of the Crescent Wing, by G. H. Lee.

4th May: SECTION LECTURE—Propellers for High-Speed Aircraft, by G. C. I. Gardiner.

20th May: MAIN LECTURE—The 42nd Wilbur Wright Memorial Lecture: The Choice of Power Units for Civil Aeroplanes, by Dr. A. E. Russell.

Divisions

Despite the many difficulties, mainly due to the large distances involved and the lack of any sizeable Aircraft Industries, the Divisions continue to thrive and the enthusiasm shown is as keen as ever.

In the Australian Division a new Branch was formed at Melbourne on 16th September 1953. It is also hoped to form a Branch at Adelaide in 1954.

The New Zealand Division with its Branches at Wellington, Auckland, Christchurch and Palmerston North is hoping to form a fifth Branch at Dunedin.

In the Southern Africa Division an effort is being made to form Branches and to overcome to some extent the territorial difficulties which they are experiencing.

Council appointed a Committee to investigate the difficulties being experienced by the Divisions, and to make recommendations whereby such difficulties might be lessened. This Committee met frequently, and was fortunate to be able to obtain information from representatives of each Division.

The Report of the Committee has been submitted to the Council, and it is under consideration at present.

Branches

Since the last Annual Report two new Branches have been formed, bringing the total number, excluding those administered by the Divisions, to twenty-five.

The Singapore Branch was founded in March 1953 and the Branch was fortunate in having Air Marshal Sir R. Owen Jones to give the inaugural address, which was on the History of the Society. In addition to numerous Lectures, the Singapore Branch has held a most successful Garden Party. Squadron Leader A. D. Miller and his Committee are to be congratulated on a very encouraging year.

In November 1953 Sir Frederick Handley Page gave the opening Lecture to the newly-formed Boscombe Down Branch. This Branch also, gives early promise of being a Branch no less successful than the others.

During the session two Memorial Lectures have been instituted, the Mitchell Memorial Lecture at Southampton, and the Barnwell Memorial Lecture at Bristol.

The first Mitchell Memorial Lecture was given by Mr. J. Smith in January 1954 and the first Barnwell Memorial Lecture was delivered by Major G. P. Bulman in March. The Lecturers spoke of the personality and work of the pioneer whom they were commemorating.

These inaugural Lectures were both classed as Main Lectures, and supplemented the normal Main Lectures at Branches, which were held at Derby, Glasgow and Belfast.

Membership

The total Membership of the Society has increased, over the past year, by about two hundred. There have been increases in every grade.

The table below shows, in detail, the Membership on 31st December 1953.

Graduates' and Students' Section

The Section has held nine Meetings during the past year and five visits were made to places of aeronautical and general engineering interest.

The Lecture programme has been noteworthy for the fact that two meetings were held in conjunction with two other Societies—the first with the London Branch of the Institute of Petroleum and the second with the Graduates' Section of the Institution of Mechanical Engineers. The latter meeting was an outstanding success for it demonstrated the interdependence of all types of engineering science. It is hoped that such meetings with other engineering societies will continue to be featured in the activities of the Section.

The Committee has continued its efforts to obtain Lectures by members of the Section, and four Lectures were given by members. Although this is less than in previous years it is not unsatisfactory.

The attendance has averaged about fifty, very close to previous average figures.

The Third Annual Reception was held at 4 Hamilton Place on 30th October. This followed the pattern of previous Receptions, dancing in the Library and Films in the Council Room.

MEETINGS DURING 1953/54

27th January 1953: A Physical Interpretation of Supersonic Flow, by R. Stanton Jones, M.A., D.C.Ae., Grad.R.Ae.S.

11th February: Production of Prototype Aircraft, by W. Thorn.

24th February: Viscount Operations, by Captain R. Rymer.

25th March: Convertible Aircraft, by J. Shapiro, Dipl.-Ing., A.F.R.Ae.S.

22nd April: Aircraft Accident Investigation, by H. Caplan, D.C.Ae., Grad.R.Ae.S.

6th October: Discussion on the Design of Light Aircraft, opened by R. Prizeman, D.C.Ae., Grad.R.Ae.S.

20th October: An Introduction to Gas Turbines, by D. H. Mallinson.

5th November: The Exploration of Space, by A. C. Clarke, B.Sc., F.R.Ae.S.

26th November: The Case for the Light Fighter, by P. A. Norman, B.Sc., Stud.R.Ae.S.

17th December: Film: Powered Flight—The Story of the Century. Joint Meeting with the London Branch of the Institute of Petroleum.

2nd February 1954: The Structural Analysis of Swept-Back Wings, by D. Howe, D.C.Ae., G.I.Mech.E., Grad.R.Ae.S. Joint Meeting with the London Graduate Section of the Institution of Mechanical Engineers.

24th February: Aircraft Plastics, by Lorne Welch.

10th March: Annual General Meeting and Film, "Powered Flight—The Story of the Century."

25th March: Airworthiness Requirements for Landing and Take-off.

29th April: Fuselage Structural Design Methods, by R. J. Jupe, A.F.R.Ae.S.

VISITS MADE DURING 1953/54

19th March 1953: *The Daily Mail* and *Daily Herald*.

18th July: U.S.A.F. Base at Wethersfield, Braintree.

26th August: The Royal Aircraft Establishment, Farnborough.

23rd September: The Bankside Power Station.

2nd December: The Royal Aircraft Establishment, Farnborough.

MEMBERSHIP AT 31st DECEMBER 1953

Grade	London Register	Australian Division	New Zealand Division	Southern Africa Division	Life and Honorary	Totals	Suspended Members (included in the foregoing figures)
Fellows ..	359 (355)	11 (12)	— (—)	1 (2)	53 (50)	424 (419)	5 (3)
Associate Fellows	2997 (2821)	106 (97)	28 (28)	38 (40)	16 (16)	3185 (3002)	57 (73)
Associates ..	1948 (1948)	75 (73)	64 (58)	74 (80)	5 (5)	2166 (2164)	125 (131)
Graduates ..	1213 (1219)	50 (48)	7 (5)	6 (4)	— (—)	1276 (1276)	42 (40)
Students ..	743 (748)	53 (55)	1 (1)	8 (8)	— (—)	805 (812)	56 (57)
Founder Members	14 (14)	— (—)	— (—)	— (—)	1 (1)	15 (15)	— (—)
Companions ..	151 (153)	6 (6)	4 (4)	3 (4)	10 (12)	174 (179)	15 (5)
Temporary Honorary Members	— (—)	— (—)	— (—)	— (—)	45 (47)	45 (47)	— (—)
	7425 (7258)	301 (291)	104 (96)	130 (138)	130 (131)	8090 (7914)	300 (309)

(Figures in brackets are corresponding figures at 31st December 1952)

Honours Awarded to Members

Not a few Members of the Society have been honoured by Her Majesty the Queen in the Coronation Honours List, and in the New Year's Honours List 1954. These the Council have much pleasure in congratulating.

Other Honours have been conferred by learned Societies and other bodies upon Members of the Society; the Council pays tribute to these recipients also.

CORONATION HONOURS

Knights Bachelor	S. Camm, C.B.E. (*Fellow*) T. O. M. Sopwith, C.B.E. (*Honorary Fellow*) W. R. Verdon Smith (*Companion*)
C.B.	E. T. Jones, O.B.E., M.Eng. (*Fellow*)
Order of St. Michael and St. George	R. E. Hardingham, O.B.E. (*Fellow*)
K.B.E.	W. Hudson Fysh, D.F.C., M.Inst.T., F.R.G.S.(A) (*Associate Fellow*) Air Marshal R. O. Jones, C.B., A.F.C., B.A., D.I.C. (*Fellow*)
C.B.E.	Group Captain Leslie Crocker (*Associate Fellow*) W. J. Duncan, D.Sc., F.R.S. (*Fellow*) A. Fage, F.R.S., A.R.C.Sc. (*Fellow*) Group Captain Bruce Robinson (*Associate Fellow*)
O.B.E.	Wing Commander R. P. Beamont, D.S.O., D.F.C. (*Associate*) G. B. Bolt (*Associate Fellow*) H. J. Curnow, B.Sc. (*Associate Fellow*) Wing Commander A. E. Davies (*Associate Fellow*) C. T. Wilkins (*Fellow*)
M.B.E.	G. Tilghman Richards (*Fellow*)

NEW YEAR'S HONOURS 1954

O.B.E.	Captain W. Baillie (*Associate Fellow*) R. K. Cushing (*Associate Fellow*)
M.V.O.	Flight Lieutenant E. W. Lamb (*Associate*)
Queen's Commendation for Valuable Service in the Air	Captain T. H. Farnsworth (*Associate Fellow*)
Air Force Cross	Squadron Leader D. de Villiers (*Graduate*)

KNIGHT OF THE MOST NOBLE ORDER OF THE GARTER

The Rt. Hon. Winston S. Churchill (*Honorary Fellow*) has been created a Knight of the Most Noble Order of the Garter.

ROYAL SOCIETY

Mr. A. A. Hall (*Fellow*) has been made a Fellow of the Royal Society.

FEDERATION AERONAUTIQUE INTERNATIONALE

Captain J. L. Pritchard, C.B.E. (*Honorary Fellow*), the late Mr. C. G. Grey (*Founder Member* and *Honorary Companion*) and Mr. A. F. Houlberg (*Associate Fellow*) were awarded the Paul Tissandier Diploma by the Federation Aeronautique Internationale for their "Services to Aviation."

THE JAMES WATT INTERNATIONAL MEDAL FOR 1953

The Institution of Mechanical Engineers has awarded Sir Harry Ricardo (*Fellow*) the James Watt International Medal for 1953 for his contributions to knowledge of the fundamental principles of Internal Combustion Engines and the application of these principles to design and development.

THE MUSICK MEMORIAL TROPHY (OF NEW ZEALAND)

The Musick Memorial Trophy (of New Zealand) has been awarded to Sir B. Melvill Jones (*Fellow*) for his life long work on the Reduction of Drag of Aircraft.

WRIGHT BROTHERS' MEMORIAL TROPHY FOR 1952

General James H. Doolittle (*Fellow*) has been awarded the Wright Brothers' Memorial Trophy. The award marks General Doolittle's "significant public service of enduring value to aviation."

CITY AND GUILDS OF LONDON INSTITUTE

The Council of the City and Guilds of London Institute have conferred the honour of Fellowship on Mr. L. P. Coombes (*Fellow*)

THE BRISTOL AND WHITE-SMITH AIR TRANSPORT MEDAL 1951-52

Mr. N. E. Rowe (*Fellow* and Member of Council) has been awarded the Bristol and White-Smith Air Transport Medal by the Institute of Transport for his paper on "Helicopter Transport in Great Britain."

INSTITUTION OF ENGINEERING DRAUGHTSMEN AND DESIGNERS

Illuminated Honours Diplomas were presented by the Institution of Engineering Draughtsmen and Designers on 31st March 1953 at a Ceremony of Awards honouring Aircraft Designers. The awards were presented to:

R. E. Bishop, C.B.E. (*Fellow*)
S. D. Davies, B.Sc. (*Fellow*)
G. R. Edwards, C.B.E., B.Sc. (*Fellow*)
H. Knowler (*Fellow*)
Dr. A. E. Russell (*Fellow*)
R. W. Walker (*Fellow*)

AMERICAN LEGION MEDAL OF MERIT

Major D. Lester Gardner (*Honorary Fellow*) has been presented with the American Legion Medal of Merit for "his many years in actively aiding in the development of aviation, especially his founding of the Institute of the Aeronautical Sciences."

SOCIETY OF LICENSED AIRCRAFT ENGINEERS' GOLD BADGE

R. E. Hardingham (*Fellow*), Secretary and Chief Executive of the Air Registration Board, has been awarded the Society of Licensed Aircraft Engineers' Gold Badge for 1952, for his paper "Some of the Responsibilities and Problems of an Airworthiness Authority."

THE DOROTHY SPICER MEMORIAL AWARD FOR 1953

R. H. Nettell (*Associate*) has been given the Dorothy Spicer Memorial Award for 1953 for his paper "A Matter of Balance."

SOCIETY OF WOMEN ENGINEERS

Miss Elizabeth G. McGill (*Fellow*) received the 1953 Award for meritorious contribution to engineering from the Society of Women Engineers at their recent National Convention in New York.

BRACKLEY MEMORIAL TROPHY

Mr. G. A. V. Tyson (*Associate Fellow*) has been awarded the Brackley Memorial Trophy by the Guild of Air Pilots in recognition of his work in connection with the "Princess" Flying Boat.

INSTITUTE OF THE AERONAUTICAL SCIENCES

The following Members of the Society have been awarded Fellowships of the Institute of the Aeronautical Sciences in 1953/54:

Mr. P. G. Masefield (*Fellow* and Vice-President)
Mr. L. P. Coombes (*Fellow*)
Monsieur Maurice Roy (*Fellow*)
Mr. N. E. Rowe (*Fellow* and Member of Council).

Sir William Farren (*Fellow* and President of the Society) and Mr. C. C. Walker (*Fellow*) have been awarded Honorary Fellowships of the Institute of the Aeronautical Sciences in 1954 and 1953.

Medals and Awards of the Society

Full particulars of the Medals and Awards of the Society were published in the August 1953 issue of the JOURNAL. The majority of these awards were presented at the Forty-First Wilbur Wright Memorial Lecture on 14th September 1953.

Journal Premium Awards

A list of Premium Awards made for 1952 was published in the August 1953 issue of the JOURNAL.

Busk Memorial Scholarship

The Busk Memorial Scholarship was awarded to Mr. B. D. Henshall for a second year, to allow him to continue his studies at Bristol University.

Royal Aeronautical Society Charter Scholarship

The Charter Scholarship for 1953/54 was awarded to Mr. J. A. H. Bailie for a second year, tenable at the College of Aeronautics, Cranfield.

Two further Charter Scholarships were awarded for the year 1953/54 to Mr. J. Waters and Mr. D. J. W. Richards for Post-Graduate Courses at the Imperial College of Science and Technology.

Geoffrey de Havilland Memorial Scholarship

The Geoffrey de Havilland Memorial Scholarship for 1953/54 was awarded to Mr. M. J. Taylor, for a second year, to allow him to continue his studies at the College of Aeronautics, Cranfield.

Society of British Aircraft Constructors' Educational Grants

The Joint Selection Committee of the Society of British Aircraft Constructors and The Royal Aeronautical Society awarded Educational Grants to the following successful candidates on 30th July 1952:—

D. Abraham	D. L. Marsden
I. R. Bayley	M. H. Radford
D. M. Bloor	C. M. W. H. Roper
M. W. Davidson	F. A. Smith

These Grants are for the assistance of young men who, for financial reasons, otherwise would be unable to obtain training in aeronautical engineering. All those awarded Society of British Aircraft Constructors' Grants are expected to qualify for a technical grade in The Royal Aeronautical Society.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to the following, who obtained the highest marks in the General Studies Examination at Halton:

Corporal Aircraft Apprentice P. E. Newton—May 1950 entry.
Aircraft Apprentice A. Mallen—September 1950 entry.

Finance

The Income and Expenditure Accounts and Balance Sheets of The Royal Aeronautical Society and Aeronautical Trusts Limited for 1953 are on pp. 286-295.

Garden Party

The Annual Garden Party was held on the 14th June 1953 at Astwick Manor, Hatfield Aerodrome, Hertfordshire. This was the first time that the Garden Party had been held at Astwick Manor, and everyone enjoyed the background of the Manor and the trees.

As this was the Jubilee Year of the First Powered Controlled Flight the machines both in the flying programme and in the static display, portrayed the history of flying, from Bleriot Monoplanes to modern Deltas.

In addition to the aeroplanes there were some engines on display.

A souvenir programme, in the form of a scrap-book covering fifty years of flying, was published.

A full report of the Garden Party was published in the August 1953 issue of the JOURNAL of the Society.

Library

237 books and sundry pamphlets have been added to the Library, and the number of loans made was increased appreciably. The lantern slide collection continues to be of value and during the Wright celebrations many requests were received for material with which to illustrate historical lectures.

Most noticeable was the increase in use made of the information service of the Library, both by members and others, by telephone and written enquiry.

The value of the historical side of the Library was emphasised in the preparation both of the Garden Party Programme and the December issue of the JOURNAL.

Some of the most valuable material added to the Library has taken the form of "scrap-books" of the early years; the Library is always ready to receive such items, as well as odd newspaper cuttings, programmes, photographs and similar material.

Part of the basement has been fitted with roller shelving and the large and valuable collection of periodicals is now more conveniently accommodated.

The Council wish to thank all those who have made donations of books and photographs to the Library.

Publications

The JOURNAL in its new size and format has been a success and many messages of congratulation have been received. The special section for Technical Notes and the summaries of Reports received in the Library have been approved by Members.

Two special issues have been published, one in June and one in December. The June JOURNAL, which coincided with the Coronation of Her Majesty Queen Elizabeth II, Patron of the Society, had a special article by Captain J. L. Pritchard on the Hodgson-Cuthbert collection illustrating early aeronautical events connected with Royalty, and a number of colour prints were reproduced. The December JOURNAL was a special issue to commemorate the Fiftieth Anniversary of Powered Controlled Flight and recorded the story of the Wright Brothers and the Society; this was also written by Captain Pritchard. This issue, which included much hitherto unpublished material, aroused much interest and a number of messages of appreciation have been received, especially from the United States.

Two numbers of the AERONAUTICAL QUARTERLY were published in 1953—in February and August. Subscriptions from non-Members of the Society continued to increase and the QUARTERLY is now distributed in thirty countries.

No new Monographs have been published, but the first three, "The Properties of Metallic Materials at Low Temperatures" by Major P. L. Teed, "The Structures and Mechanical Properties of Metals" by Dr. Bruce Chalmers (reprinted in 1953) and "Adhesives for Wood" by R. A. G. Knight, have continued to sell and a fourth Monograph, "Massbalancing of Aircraft Control Surfaces" by H Templeton, will be published in 1954. Several more are in hand.

Data Sheets continued to be brought up to date and re-issued in new editions. New issues of Performance, Structures and Aerodynamics Data Sheets were made during the year. There were 10 new Performance, 27 new Structures, and 11 new Aerodynamics Sheets, in addition to a considerable programme of checking and re-printing of existing Aerodynamics and Structures Sheets.

Donations

During the year the Society received donations from:

Blackburn and General Aircraft Ltd.
Bristol Aeroplane Co. Ltd.
de Havilland Aircraft Co. Ltd.
Dowty Equipment Ltd.
Folland Aircraft Ltd.
Hawker Siddeley Group Ltd.
Sir George Nelson (Chairman, English Electric Co. Ltd.)
Sir Frederick Handley Page
Percival Aircraft Ltd.
Rolls-Royce Ltd.
Society of British Aircraft Constructors
Ministry of Supply
Vickers-Armstrongs Ltd.
Westland Aircraft Ltd.

These the Council wish to acknowledge with gratitude and thanks. They also wish to acknowledge the contributions from the Ministry of Supply and the Society of British Aircraft Constructors for the work of the Technical Committees of the Society.

Anglo-American Aeronautical Conference

The Fourth Anglo-American Aeronautical Conference was held in London from the 15th to 17th September 1953. The number of delegates reached a record figure of 729 and this proves that these Conferences are being accepted as a useful medium for the interchange of information and ideas.

It has been decided that the Fifth Conference will be held in Los Angeles in June 1955.

(A full report of the Conference was published in the November 1953 issue of the JOURNAL of the Society.)

Officers and Committees

In January 1954 Mr. C. F. Uwins, owing to his heavy business commitments, regretfully resigned from the Honorary Treasureship, an office which he had filled, with success, for the past eight years. The Council of the Society has appreciated very much the work of Mr. Uwins; the finances of the Society reflect his work and its success.

The Council are fortunate in having Major G. P. Bulman as the new Honorary Treasurer, and welcome him to this office.

The duties of the Committees do not become less onerous and the Council wish to record its appreciation of the work of each Committee, work which involves the expenditure of considerable time and energy.

Nash Collection of Veteran Aircraft

1953 closed with the purchase of the Nash Collection by the Society; this purchase happened quite fortuitously, but it fitted the temper of the year with an exactness which could not be bettered. It has met with enthusiastic approval, which has prompted many congratulatory messages and letters.

It is hoped that Members of the Society will have the opportunity of viewing the Collection at the next Garden Party on 13th June 1954.

50th Anniversary of Powered Controlled Flight

The Royal Aero Club and the Society combined to celebrate the 50th Anniversary of Powered Controlled Flight by holding a Dinner at the Dorchester on the 17th December 1953. This was well attended, almost 900 Members and Guests being present.

The Dinner was followed by the historical film "Powered Flight—The Story of the Century," which was compiled from authentic material collected by the Shell Film Unit in conjunction with the Society. The film was envisaged more than two years ago as a commemoration of the historic year 1953, and it was based on the research carried out for the Society by the Film Centre. This foresight resulted in a memorable film which has had many appreciative and enthusiastic audiences, since it was shown at the Commemorative Dinner. It is still in demand, and the Society takes pride and pleasure in distributing this fine film, which, it can be said with exactness, it first suggested. The thanks of the Council go to the Shell Film Unit who agreed with the suggestion, and produced Powered Flight—indeed the Story of the Century.

Staff

The Staff has been increased slightly over the past months, and it is with pleasure that the Council give a special welcome to Mr. J. Solvey, seconded by the Australian Government, for temporary service with the Technical Department.

The work of the Staff has been especially arduous over the past fifteen months, and, although all the Staff have worked well, the Council feel that mention must be made of the willing and loyal assistance given to the Secretary by Miss Barwood, Mrs. Bradbrooke, Mr. D. C. Smith and Miss Voyce.

Associate Fellowship Examination

The Associate Fellowship Examination of the Society is growing in importance. There were over 100 Candidates in the May 1953 entry at home and abroad. In December 1953 there were some 60 Candidates.

The following are among the countries abroad in which the examination was held:

Australia	New Zealand	Belgium
Canada	India	United States
South Africa	Pakistan	South America
Ceylon	Holland	

An announcement was made in the August 1953 JOURNAL regarding the change in the Associate Fellowship Examination Syllabus. Over the years the standard of the Syllabus has risen, and with the new Syllabus it is felt that the standard will be of a very high order.

General

During the period under review the Society's building has been of increased value to a number of aeronautical organisations who have made use of the Committee Rooms and Lecture facilities. The Society has an extremely good epidiascope and a 16 m.m. cinematograph projector, both of which have been in constant use during the year. The Committee Rooms and Library have been regularly used by the Aircraft Recognition Society, the Aeronautical Research Council, the Society of British Aircraft Constructors, the Helicopter Association and the College of Aeronautics.

The Library has continued to be used for the Society's Section Lectures, and for the Graduates' and Students' Section Lectures.

Obituaries

The Council regret to record the death of the following Members of the Society:—

Captain P. D. Acland (*Companion*)
D. R. Brodie (*Student*)
Air Chief Marshal Sir Robert Brooke-Popham (*Fellow*)
B. H. M. Buck (*Associate Fellow*)
H. V. Bullbrook (*Associate*)
G. F. Davidson (*Associate Fellow*)
C. Davies (*Associate*)
F. Emsley (*Associate Fellow*)
Air Chief Marshal Sir Wilfred Freeman (*Fellow*)
A. L. Gilmore (*Associate*)
C. G. Grey (*Honorary Companion* and *Founder Member*)
L. E. Hartridge (*Associate*)
Captain J. S. Irving (*Fellow*)
W. P. Kemp (*Associate Fellow*)
Lord Kenilworth (*Fellow*)
Sir Hew Kilner (*Honorary Companion*)
P. G. Lawrence (*Associate*)
T. J. McTear (*Associate*)
R. C. Margetts (*Student*)
Flight Lieutenant M. C. B. Mitchell (*Student*)
C. V. Murray (*Associate Fellow*)
Squadron Leader R. H. H. Pelling (*Associate Fellow*)
G. L. P. Phillips (*Associate*)
Professor Dr. Ludwig Prandtl (*Honorary Fellow*)
Sub-Lieutenant B. E. Rayner (*Graduate*)
Flying Officer A. S. Ryde (*Graduate*)
R. M. Siely (*Student*)
T. B. Stelling (*Associate*)
A. J. E. Thornton (*Associate Fellow*)
E. A. Vessey (*Associate Fellow*)
F. L. Worn (*Associate Fellow*)

THE ROYAL

(INCORPORATED

BALANCE SHEET

1952 Figures		£ s. d.	£ s. d.
	Current Liabilities—		
4492 13 9	Sundry Creditors	8124 14 9	
4434 11 2	Subscriptions and other amounts received in advance ...	3783 1 1	11907 15 10
8,927 4 11			
	Surplus—(Subject to depreciation of Investments)		
2680 3 10	*Publications Development Account*	— — —	
2000 0 0	*Reserve for Anglo-American Conferences*	2000 0 0	
	Income and Expenditure Account—		
4617 19 3	Balance at 31st December 1952 ... ... 6814 10 9		
	Add Publications Development Account—		
	Balance at 31st December 1952 transferred 2680 3 10		
	9494 14 7		
2196 11 6	*Add* Surplus of Income over Expenditure for year to date 3678 0 3	13172 14 10	15172 14 10
11494 14 7			
£20421 19 6			£27080 10 8

W. S. FARREN, *President.*
G. P. BULMAN, *Honorary Treasurer.*

REPORT OF THE AUDITORS TO THE MEMBERS OF

In our opinion and to the best of our information and according to the explanations given Society together with the accounts of the Royal Aeronautical Society Endowment Fund of the state of the Society's affairs as at 31st December 1953 and of its surplus for the year

We have obtained all the information and explanations which to the best of our know proper books of account and the above mentioned accounts are in agreement therewith.

3 Frederick's Place, Old Jewry, London, E.C.2. *11th March 1954.*

INCOME AND EXPENDITURE ACCOUNT FOR

1952 Figures		£ s. d.	£ s. d.
£ s. d.			
1631 16 7	To Establishment Charges—		
	Ground Rent, Heating, Lighting, Insurance and Repairs		2556 19 7
	„ Office and Staff Expenses—		
8741 17 4	Salaries	9637 5 9	
1401 4 7	Staff Pensions Premiums and Pensions Paid	1379 12 6	
1564 17 10	Printing and Stationery	1934 12 9	
1304 7 2	Postages and Telephones	1368 19 0	
168 15 4	Office Equipment	694 4 7	
725 3 9	Other Charges	954 8 2	15969 2 9
13906 6 0			
5635 17 0	„ Journal and Publications		3871 11 10
	„ Expenditure on Data Sheets—		
— — —	*Less* amounts recoverable		82 0 0
423 0 9	„ Meetings		540 3 7
2000 0 0	„ Anglo-American Aeronautical Conference 1953		1930 7 1
476 13 6	„ Garden Party		1053 16 10
495 3 8	„ Dinners and Receptions		443 19 8
— — —	„ Commemorative Dinner 17th December 1953		232 14 4
— — —	„ Expenditure on Film " Powered Flight "		500 0 0
1653 15 10	„ Library Expenses		1953 8 9
455 0 0	„ Branch Expenses		490 0 0
257 15 6	„ Prizes and Donations		145 2 0
216 13 4	„ Charter Scholarships		383 6 8
217 4 10	„ Legal and Professional Charges		202 10 10
1000 0 0	(Donation to Pritchard Testimonial Fund)		
	„ Balance, being surplus of Income over Expenditure for year		
2196 11 6	carried to Balance Sheet		3678 0 3
£30565 18 6			£34033 4 2

AERONAUTICAL SOCIETY

BY ROYAL CHARTER 1949)

31st DECEMBER 1953

1952 Figures				£ s. d.	£ s. d.
			Current Assets—		
1 0 0			Stock of Journals and other Publications	1 0 0	
6640 2 11			Sundry Debtors	11661 0 9	
544 9 11			Payments in Advance	228 14 2	
4070 7 9			Cash at Bank and in Hand	6018 17 0	17909 11 11
11256 0 7					
7801 4 2			*Investments at Cost*		7801 4 2
			Market value 31st December 1953: £7,392 (1952: £6,979)		
			Aeronautical Trusts Limited—		
1 1 0			21 shares of 1/- each fully paid at cost	1 1 0	
1313 13 9			Amount due on current account	1318 13 7	1319 14 7
1314 14 9					
			Printed Books, Binding, Old Prints, etc.—		
50 0 0			At nominal amount		50 0 0
£20421 19 6					£27080 10 8

MBERS OF THE ROYAL AERONAUTICAL SOCIETY

anations given to us, the above balance sheet and the annexed income and expenditure account of the
t Fund included in the annexed accounts of Aeronautical Trusts Limited give a true and fair view
for the year ended on that date.
of our knowledge and belief were necessary for our audit. In our opinion the Society has kept
erewith.

(*Signed*) PRICE WATERHOUSE & CO.

FOR THE YEAR ENDED 31st DECEMBER 1953

1952 Figures				£ s. d.	£ s. d.
22541 6 0			By Annual Subscriptions		23891 14 11
2626 17 8			„ Donations		4764 19 7
118 17 4			„ Interest on Investments (*Less* Tax)	134 16 6	
106 15 9			„ Income Tax Recovered	107 10 4	
			„ Surplus on Endowment Fund Income and Expenditure		
4996 0 1			Account for year	5083 11 4	5325 18 2
5221 13 2					
176 1 8			„ Examinations		50 11 6
£30565 18 6					£34033 4 2

AERONAUTICAL

BALANCE SHEET

1952 Figures £ s. d.		£ s. d.	£ s. d.	£ s. d.
	SHARE CAPITAL—			
	Authorised—40 shares of 1s. each		2 0 0	
1 1 0	*Issued*—21 shares of 1s. each fully paid			1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND—			
	Capital Account—(Subject to depreciation of Investments)			
132152 11 1	Balance at 31st December 1952		132774 11 1	
7 7 0	*Add*—Donations received during year		5 0 0	
614 13 0	Entrance Fees received during year		710 17 0	
132774 11 1			133490 8 1	
	Income Account—			
9103 14 6	Balance as at 31st December 1952		9103 14 6	142594 2 7
141878 5 7				
	PILCHER MEMORIAL FUND—			
	Capital Account—			
99 14 0	As at 31st December 1952		99 14 0	
	Income Account—			
79 16 8	Balance at 31st December 1952 ...	85 4 0		
5 7 4 (Income)	*Less*—Excess of Expenditure over Income for year to date	5 2 8	80 1 4	179 15 4
184 18 0				
	USBORNE MEMORIAL FUND—			
	Capital Account—			
109 2 5	As at 31st December 1952		109 2 5	
	Income Account—			
88 6 4	Balance at 31st December 1952 ...	94 5 8		
5 19 4 (Income)	*Less*—Excess of Expenditure over Income for year to date	4 10 8	89 15 0	198 17 5
203 8 1				
	HERBERT AKROYD STUART FUND—			
	Capital Account—			
691 9 0	As at 31st December 1952		691 9 0	
	Income Account—			
598 4 1	Balance at 31st December 1952 ...	614 15 11		
16 11 10	*Add*—Surplus of Income over Expenditure for year to date	17 18 4	632 14 3	1324 3 3
1306 4 11				
	R.38 MEMORIAL FUND—			
	Capital Account—			
981 13 10	As at 31st December 1952		981 13 10	
	Income Account—			
987 0 4	Balance at 31st December 1952 ...	1045 19 6		
58 19 2	*Add*—Income for year to date ...	60 17 0	1106 16 6	2088 10 4
2027 13 4				
145601 10 11	*Forward*			146386 9 11

TRUSTS LIMITED

31st DECEMBER 1953

1952 Figures				£ s. d.	£ s. d.	£ s. d.
1 1 0	CASH IN HAND					1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND—					
	Leasehold Property at cost *less* amounts written off					
	4, 8, and 9, Hamilton Place					
14185 1 9	At cost			14185 1 9		
7126 1 9	*Less*—Amortisation written off to date			7781 1 9	6404 0 0	
7059 0 0						
	Furniture at cost *less* depreciation					
4794 13 0	At cost			6173 10 6		
2955 13 0	*Less*—Depreciation written off to date			3264 10 6	2909 0 0	
1839 0 0						
132065 11 3	Investments at cost				132065 11 3	
	Market value 31st December 1953, £117,537 (1952, £109,027), including £1,000 2½% Defence Bonds (unquoted) at cost					
140963 11 3					141378 11 3	
	Current Assets—					
750 0 0	Sundry Debtors			750 0 0		
1478 8 1	Cash at Bank			1784 4 11	2534 4 11	
143191 19 4					143912 16 2	
	Less—Amount due to the Royal Aeronautical Society				1318 13 7	142594 2 7
141878 5 7						
	PILCHER MEMORIAL FUND—					
156 5 0	Investment at cost				156 5 0	
	Market value 31st December 1953: £131 (1952: £120)					
28 13 0	Cash at Bank				23 10 4	179 15 4
184 18 0						
	USBORNE MEMORIAL FUND—					
174 11 1	Investment at cost				174 11 1	
	Market value 31st December 1953: £145 (1952: £133)					
28 17 0	Cash at Bank				24 6 4	198 17 5
203 8 1						
	HERBERT AKROYD STUART FUND—					
1102 15 8	Investments at cost				1278 11 1	
	Market value 31st December 1953: £1,092 (1952: £838)					
203 9 3	Cash at Bank				45 12 2	1324 3 3
1306 4 11						
	R.38 MEMORIAL FUND—					
1754 6 2	Investments at cost				2004 18 9	
	Market value 31st December 1953: £1,688 (1952: £1,314)					
273 7 2	Cash at Bank				83 11 7	2088 10 4
2027 13 4						
145601 10 11	*Forward*					146386 9 11

AERONAUTICAL

BALANCE SHEET

1952 Figures £ s. d.		£ s. d.	£ s. d.	£ s. d.
145601 10 11	*Forward*			146386 9 11
	EDWARD BUSK MEMORIAL FUND—			
	Capital Account—			
449 6 1	As at 31st December 1952		449 6 1	
	Income Account—			
233 13 9	Balance at 31st December 1952 ...	239 5 3		
5 11 6	*Add*—Surplus of Income over Expenditure for year to date	3 10 4	242 15 7	692 1 8
688 11 4				
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS—			
	Capital Account—			
5417 5 4	Balance at 31st December 1952		5417 5 4	
	Add—Premium received on conversion of Defence Bonds		1 5 0	
			5418 10 4	
	Income Account—			
— — —	Balance at 31st December 1952 ...	103 1 6		
103 1 6	*Add*—Surplus of Income over Expenditure for year to date	44 7 0	147 8 6	5565 18 10
5520 6 10				
	WILBUR WRIGHT MEMORIAL FUND—			
	Capital Account—			
2136 17 11	As at 31st December 1952		2136 17 11	
	Income Account—			
225 9 2	Balance at 31st December 1952 ...	231 7 6		
5 18 4 (Surplus)	*Less*—Excess of Expenditure over Income for year to date	28 18 0	202 9 6	2339 7 5
2368 5 5				
	SIMMS GOLD MEDAL FUND—			
	Capital Account—			
527 15 9	As at 31st December 1952		527 15 9	
	Income Account—			
73 9 9	Balance at 31st December 1952 ...	82 11 3		
9 1 6	*Add*—Surplus of Income over Expenditure for year to date	10 5 6	92 16 9	620 12 6
610 7 0				
	ALSTON MEMORIAL FUND—			
	Capital Account—			
245 6 0	As at 31st December 1952		245 6 0	
	Income Account—			
77 8 11	Balance at 31st December 1952 ...	81 7 1		
3 18 2 (Surplus)	*Less*—Excess of Expenditure over Income for year to date	1 1 10	80 5 3	325 11 3
326 13 1				
155115 14 7	*Forward*			155930 1 7

TRUSTS LIMITED—*Continued*

31st DECEMBER 1953

1952 Figures £ s. d.		£ s. d.	£ s. d.	£ s. d.
145601 10 11	*Forward*			146386 9 11
	EDWARD BUSK MEMORIAL FUND—			
658 8 8	Investments at cost		658 8 8	
	Market value 31st December 1953: £628 (1952: £575)			
30 2 8	Cash at Bank		33 13 0	692 1 8
688 11 4				
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS—			
4806 10 0	Investments at valuation 31st December 1951		4806 10 0	
	Investment at cost		601 6 6	
			5407 16 6	
	Market value 31st December 1953: £5,615 (1952: £4,675)			
713 16 10	Cash at Bank		158 2 4	5565 18 10
5520 6 10				
	WILBUR WRIGHT MEMORIAL FUND—			
2250 14 9	Investments at cost		2250 14 9	
	Market value 31st December 1953: £2,184 (1952: £2,029)			
117 10 8	Cash at Bank		88 12 8	2339 7 5
2368 5 5				
	SIMMS GOLD MEDAL FUND—			
504 12 0	Investments at cost		585 0 0	
	Market value 31st December 1953: £517 (1952: £403)			
105 15 0	Cash at Bank		35 12 6	620 12 6
610 7 0				
	ALSTON MEMORIAL FUND—			
290 0 0	Investments at cost		290 0 0	
	Market value 31st December 1953: £290 (1952: £283)			
36 13 1	Cash at Bank		35 11 3	325 11 3
326 13 1				
155115 14 7	*Forward*			155930 1 7

AERONAUTICAL

BALANCE SHEET

1952 Figures							
£	s.	d.		£	s. d.	£	s. d.
155115	14	7	*Forward*			155930	1 7
			GEOFFREY DE HAVILLAND MEMORIAL FUND—				
			Capital Account—				
4175	17	5	As at 31st December 1952			4175 17 5	
			Income Account—				
325	4	8	Balance at 31st December 1952 ...	326 10 10			
			Add—Surplus of Income over Expenditure for year to date	3 4 0		329 14 10	4505 12 3
1	6	2					
4502	8	3					
£159618	2	10					£160435 13 10

REPORT OF THE AUDITORS TO THE

In our opinion and to the best of our information and according to the explanations a true and fair view of the state of the Company's affairs and of the Funds administered by it We have obtained all the information and explanations which to the best of our proper books of account and the above mentioned accounts, which are in agreement therewith,

3 Frederick's Place, Old Jewry, London, E.C.2. *11th March 1954.*

AERONAUTICAL

INCOME AND EXPENDITURE ACCOUNTS

ROYAL AERONAUTICAL SOCIETY

1952 Figures					
£	s.	d.		£	s. d.
655	0	0	To Amortisation of Leasehold Property	655	0 0
239	8	0	„ Depreciation of Furniture	308	17 6
5	5	0	„ Legal Expenses	8	8 0
4996	0	1	„ Surplus of Income over Expenditure for year transferred to Royal Aeronautical Society	5083	11 4
£5895	13	1		£6055	16 10

PILCHER

£	s.	d.		£	s. d.
—	—	—			
5	7	4	To 1953 Award	10	10 0
(Income)					
£5	7	4		£10	10 0

USBORNE

£	s.	d.		£	s. d.
—	—	—			
5	19	4	To 1953 Award	10	10 0
(Income)					
£5	19	4		£10	10 0

HERBERT AKROYD

£	s.	d.		£	s. d.
21	0	0	To 1953 Award	21	0 0
16	11	10	„ Surplus of Income over Expenditure for year carried to Balance Sheet ...	17	18 4
£37	11	10		£38	18 4

TRUSTS LIMITED—*Continued*

31st DECEMBER 1953

1952 Figures						
£	s.	d.		£ s. d.	£ s. d.	£ s. d.
155115	14	7	*Forward*			155930 1 7
			GEOFFREY DE HAVILLAND MEMORIAL FUND—			
4175	17	5	Investments at cost		4426 10 0	
			Market value 31st December 1953: £3,879 (1952: £3,397)			
326	10	10	Cash at Bank		79 2 3	4505 12 3
4502	8	3				
£159618	2	10				£160435 13 10

MEMBERS OF AERONAUTICAL TRUSTS LTD.

given to us the above balance sheet and the annexed income and expenditure account give as at 31st December 1953 and of the surplus of the Funds for the year ended on that date. knowledge and belief were necessary for our audit. In our opinion the company has kept give in the prescribed manner the information required by the Companies Act, 1948.

(*Signed*) PRICE WATERHOUSE & CO.

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1953

ENDOWMENT FUND

1952 Figures				
£	s.	d.		£ s. d.
2642	1	4	By Interest on Investments (Gross)	2642 1 4
969	7	3	„ Interest on Investments (*less* tax)	1054 1 2
784	4	6	„ Refund of Income Tax	859 14 4
1500	0	0	„ Rents Receivable	1500 0 0
£5895	13	1		£6055 16 10

MEMORIAL FUND

£	s.	d.		£ s. d.
5	7	4	By Interest on Investments (Gross)	5 7 4
—	—	—	„ Excess of Expenditure over Income for year carried to Balance Sheet ...	5 2 8
£5	7	4		£10 10 0

MEMORIAL FUND

£	s.	d.		£ s. d.
5	19	4	By Interest on Investments (Gross)	5 19 4
—	—	—	„ Excess of Expenditure over Income for year carried to Balance Sheet ...	4 10 8
£5	19	4		£10 10 0

STUART FUND

£	s.	d.		£ s. d.
37	11	10	By Interest on Investments (Gross)	37 11 10
—	—	—	„ Interest on Investments (*less* tax)	1 6 6
£37	11	10		£38 18 4

AERONAUTICAL

INCOME AND EXPENDITURE ACCOUNTS

R.38

1952 Figures				
£	s.	d.		£ s. d.
58	19	2	To Income for year carried to Balance Sheet	60 17 0
£58	19	2		£60 17 0

EDWARD BUSK

£	s.	d.		£ s. d.
21	0	0	To 1953 Award	21 0 0
5	11	6	„ Surplus of Income over Expenditure for year carried to Balance Sheet ...	3 10 4
£26	11	6		£24 10 4

EDWARD BUSK STUDENTSHIP

£	s.	d.		£ s. d.
55	0	0	To 1953 Award	165 0 0
103	1	6	„ Surplus of Income over Expenditure for year carried to Balance Sheet ...	44 7 0
£158	1	6		£209 7 0

WILBUR WRIGHT

£	s.	d.		£ s. d.
75	0	0	To 1953 Award	100 0 0
5	18	4	(Surplus)	
£80	18	4		£100 0 0

SIMMS GOLD

£	s.	d.		£ s. d.
7	5	10	To 1953 Award	6 14 0
9	1	6	„ Surplus of Income over Expenditure for year carried to Balance Sheet ...	10 5 6
£16	7	4		£16 19 6

ALSTON

£	s.	d		£ s. d.
5	0	0	To 1953 Award	10 0 0
3	18	2	(Surplus)	
£8	18	2		£10 0 0

GEOFFREY de HAVILLAND

£	s.	d.		£ s. d.
120	0	0	To 1953 Award	120 0 0
1	6	2	„ Surplus of Income over Expenditure for year carried to Balance Sheet ...	3 4 0
£121	6	2		£123 4 0

TRUSTS LIMITED—*Continued*

FOR THE YEAR ENDED 31st DECEMBER 1953

MEMORIAL FUND

1952 Figures				1953		
£	s.	d.		£	s.	d.
58	19	2	By Interest on Investments (Gross)	58	19	2
—	—	—	„ Interest on Investments (*less* tax)	1	17	10
£58	19	2		£60	17	0

MEMORIAL FUND

£	s.	d.		£	s.	d.
20	3	8	By Interest on Investments (Gross)	24	10	4
2	5	6	„ Interest on Investments (*less* tax)	—	—	—
4	2	4				
(Refund of Income Tax)						
£26	11	6		£24	10	4

IN AERONAUTICS

£	s.	d.		£	s.	d.
126	11	9	By Interest on Investments (Gross)	134	11	5
31	9	9	„ Interest on Investments (*less* tax)	38	2	4
—	—	—	„ Refund of Income Tax	36	13	3
£158	1	6		£209	7	0

MEMORIAL FUND

£	s.	d.		£	s.	d.
80	18	4	By Interest on Investments (Gross)	59	2	0
—	—	—	„ Interest on Investments (*less* tax)	12	0	0
—	—	—	„ Excess of Expenditure over Income for year carried to Balance Sheet ...	28	18	0
£80	18	4		£100	0	0

MEDAL FUND

£	s.	d.		£	s.	d.
16	7	4	By Interest on Investments (Gross)	16	7	4
—	—	—	„ Interest on Investments (*less* tax)		12	2
£16	7	4		£16	19	6

MEMORIAL FUND

£	s.	d.		£	s.	d.
8	18	2	By Interest on Investments (Gross)	8	18	2
—	—	—	„ Excess of Expenditure over Income for year carried to Balance Sheet ...	1	1	10
£8	18	2		£10	0	0

MEMORIAL FUND

£	s.	d.		£	s.	d.
121	6	2	By Interest on Investments (Gross)	121	6	2
—	—	—	„ Interest on Investments (*less* tax)	1	17	10
£121	6	2		£123	4	0

TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

Tubes of Optimum Bending Stiffness: An Analogy

by

H. B. HOWARD, B.A., B.Sc., F.R.Ae.S.
(Ministry of Supply)

1. Introduction

The torsional stiffness of a thin-walled tube of given perimeter and thickness varies as the square of the enclosed area. The shape giving maximum torsional stiffness is therefore a circle, this being the curve with maximum area for given perimeter. We consider here the nature of the corresponding curve for maximum bending stiffness. The quantity to be made a maximum is now, not the area within the curve, but the second moment for the whole curve about the bending axis. This will give the greatest "moment of inertia" for a tube of uniform thickness. The theory is given in the Appendix and typical forms are shown in Fig. 3. A finite length of base has to be assumed; otherwise the curve reduces to a single straight line normal to the axis.

2. Rotational Analogy

The interesting point about this optimum curve is that it is identical with the shape taken up by a skipping rope, turning fast enough for gravity forces to be neglected.

This analogy enables the optimum shape to be readily visualised. As the ratio of length to base increases from unity to infinity the form changes from a sine curve to an elongated top hat. Unfortunately the curve is not an elementary form and tables of elliptic functions have to be used to obtain the co-ordinates. Expressions connecting the length, base, height and "moment of inertia" of the curve are derived in the Appendix and represented graphically in Fig. 5.

The optimum can easily be compared with other shapes from this diagram. For example (*see* Figs. 2 and 5) for $L/a=\pi/2$, $k=0{\cdot}62$ and $I/a^3=0{\cdot}862$. This gives the optimum shape of the same perimeter as a circle for which I/a^3 (for a quadrant) is $\pi/4\,(=0{\cdot}785)$ so that the inertia has gone up in the ratio 1·11, *i.e.* by 11 per cent. For a rectangular tube with height twice the width, the increase in inertia is about 26 per cent.

3. The General Case

This "skipping rope" analogy is really self-evident, as following a general principle. Imagine a string of negligible mass with any number of point masses $m_1, m_2, \ldots$ attached to it at any arbitrary spacing. The ends of the string are attached to points on the x-axis and the whole rotated with angular velocity ω. Let $y_1, y_2, \ldots$ be the distances from the x-axis of the masses $m_1, m_2, \ldots$ in the steady state. Then by D'Alembert's principle the shape will be the same as that taken up when the string is at rest and parallel forces $m_1\omega^2 y_1$, $m_2\omega^2 y_2, \ldots$ are applied to the masses at right angles to the axis. This shape will be the same as that of the string hanging under gravity with masses $m_1\omega^2 y_1/g$, $m_1\omega^2 y_2/g, \ldots$ replacing $m_1, m_2, \ldots$, and will therefore meet the condition that the centre of gravity of all the masses is at the lowest point, that is

$$\Sigma\,(m\omega^2 y^2/g)$$

is a maximum and therefore

$$\Sigma\,(my^2)$$

is a maximum.

Any flexible string with any mass distribution will therefore set itself to the configuration giving maximum inertia.

A heavy longitudinal member in the beam can be regarded as the equivalent of a point mass on the string and the optimum section for beams which include such members can still be found. Shapes such as those shown in Fig. 4 for one or two longitudinals on each side of the axis can be obtained in this way.

Such shapes could be determined experimentally by constructing a sort of necklace and observing its shape when rotated rapidly. The mass per unit length of the string would correspond to the thickness of the skin and the mass of the beads to the area of the longitudinals. The slope of the section will change discontinuously at each longitudinal where there will always be a ridge. This follows from the rotational analogy from which it is also evident that the section can never meet the x-axis at right angles but is always inwardly directed at the intersection.

Polygonal sections could be derived by using a system of jointed rods instead of beads on a string.

4. Stability of Section in Bending

When a thin-walled tube is bent into the arc of a circle, the longitudinal stresses produce a force on each element proportional to its area and to its distance from the neutral axis and directed towards that axis. This system of loading tends to flatten the section by transverse bending of the skin. This flattening reduces the

Received 20th January 1954.

moment of inertia and leads eventually to complete collapse (the Brazier effect).

If the application to optimum sections is considered it is at once apparent that these flattening loads are identical in relative magnitude and distribution with the inertia forces on the skipping rope, but are opposite in direction. It follows that the optimum section will carry these loads as a compression arch provided that the two ends on the neutral axis are held fixed relatively, so that outwards spreading is prevented. The compression in the arch corresponds to the tension in the rope. The section will thus not distort, the bending action tending only to produce a small transverse compression in the

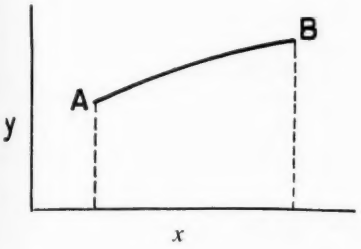


FIGURE 1.

skin. This will apply to any optimum section with or without longitudinals. The section will have an instability condition as a compression arch but as the loads are small this is unlikely to be critical in any practical tube.

If a wing or fuselage is built to this optimum section the ribs or frames will provide diametral constraint and such a component is likely to show a high resistance to what is sometimes called "general instability." It follows also that the compressing or distorting action on the ribs will be reduced by the use of such sections, the direct stresses in the skin producing a chordwise tension in the ribs.

The departure of a section from the optimum form will give some indication of the amount of distortion to be expected. Circular or square sections, for example, show up unfavourably in this respect.

5. Conclusion

A final word of warning may be advisable. These sections do not give least bending stress for a given area, nor do they give the best shape for a fixed maximum depth. They give simply the greatest stiffness for a given base, length and area distribution. The practical implications have not been followed up, the purpose being simply to draw attention to this analogy and to the special properties of sections derived by it. The deduction that these optimum tubes will not distort under bending is perhaps worthy of experimental study.

ACKNOWLEDGMENT

The author is grateful to Dr. D. M. A. Leggett for a number of helpful suggestions in the preparation of this paper, and to the Chief Scientist, Ministry of Supply, for permission to publish the paper.

APPENDIX

1. THE ARC OF MAXIMUM SECOND MOMENT FOR GIVEN LENGTH

It is required to find (Fig. 1) the form of the arc passing through fixed points A and B and of constant length between them, such that,

$$\int_A^B y^2 ds \quad \text{is a maximum.}$$

From the calculus of variations we have that, if $F(x, y, p)$ and $G(x, y, p)$ are functions of x, y and p $(=dy/dx)$ then the condition that $\int_{x_1}^{x_2} F(x, y, p)\,dx$ is a maximum (or minimum) while $\int_{x_1}^{x_2} G(x, y, p)\,dx$ is held constant, is given by

$$0=\frac{\partial F}{\partial y}-\lambda\frac{\partial G}{\partial y}-\frac{d}{dx}\left(\frac{\partial F}{\partial p}\right)+\lambda\frac{d}{dx}\left(\frac{\partial G}{\partial p}\right). \qquad (1)$$

x, y and p are treated as independent variables and λ is a constant depending on the particular conditions.

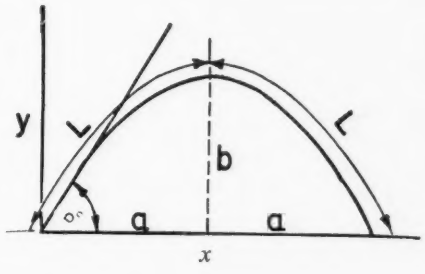


FIGURE 2.

In the present problem,

$$F(x, y, p)=y^2\frac{ds}{dx}=\sqrt{(1+p^2)}\,y^2$$

$$G(x, y, p)=\sqrt{(1+p^2)}.$$

Writing for brevity,

$$P=\sqrt{(1+p^2)},\quad P'=dP/dp,\quad P''=d^2P/dp^2$$

$$F=y^2P,\quad G=P,$$

(1) becomes

$$0=2yP-2ypP'-y^2pP''\frac{dp}{dy}+\lambda pP''\frac{dp}{dy}$$

$$\text{so that}\quad -\frac{2ydy}{\lambda-y^2}=\frac{pP''dp}{P-pP'};$$

Integrating and reducing, we obtain as the basic differential equation,

$$\sqrt{(1+p^2)}=A(\lambda-y^2). \qquad (3)$$

where A is a constant of integration.

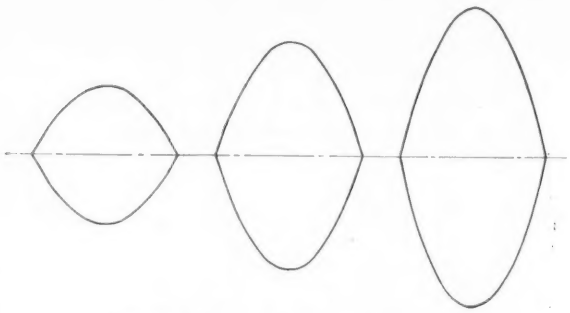


FIGURE 3. Typical optimum sections.

2. SKIPPING ROPE ANALOGY

Before solving (3), we show that the equation to a skipping rope rotating at such speed that gravity forces are negligibly small, has an identical form. For such a rope rotating about the axis of x with angular velocity ω and of constant mass m per unit length, the equations of equilibrium, for an element where the tension is T and $p=\tan\psi$, are

$$d(T\cos\psi)=0$$

$$d(T\sin\psi)=-m\omega^2 y\,ds,$$

so that $T\cos\psi=H=\text{constant}$,

$$d(\tan\psi)=-\frac{m\omega^2}{H}\,y\,ds,$$

and hence
$$\frac{p\,dp}{\sqrt{(1+p^2)}}=-\frac{m\omega^2}{H}\,y\,dy$$

and
$$\sqrt{(1+p^2)}=A'-\frac{m\omega^2}{2H}\,y^2. \quad . \quad . \quad (4)$$

This is identical in form with (3). As $m\omega^2/(2H)$ has the dimensions L^{-2} this is a purely geometrical relation and the shape of the rope depends only on its length and the position of the points of attachment.

3. SOLUTION OF BASIC EQUATION

This is solved for the symmetrical case (Fig. 2), when the two ends of the arc lie at the ends of the base line of (known) length $2a$, the arc being of (known) length $2L$. This is of most practical interest. We write b for the height at the centre and $\pm p_0$ for the slopes at the two ends and define

$$\left.\begin{aligned}1+p_0^2&=n^2\\ \frac{n-1}{n+1}&=k^2\end{aligned}\right\}. \quad . \quad . \quad . \quad . \quad (5)$$

We can now express A and λ in equation (3) in terms of b and k^2 and obtain

$$\left(\frac{dy}{dx}\right)^2=p^2=\left(\frac{2k}{1-k^2}\right)^2\left(1-\frac{y^2}{b^2}\right)\left(1-k^2\frac{y^2}{b^2}\right),$$

i.e.
$$\frac{1-k^2}{2k}\,\frac{d(y/b)}{\sqrt{\left[\left(1-\frac{y^2}{b^2}\right)\left(1-k^2\frac{y^2}{b^2}\right)\right]}}=\frac{dx}{b}.$$

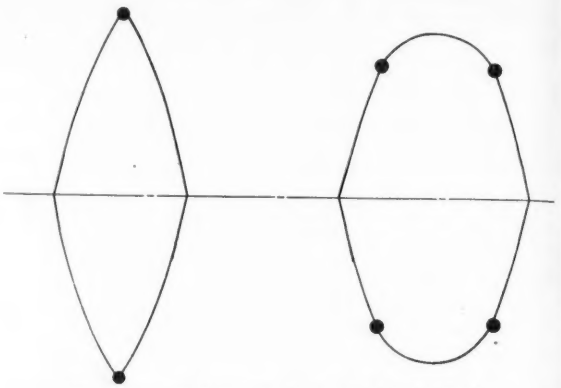


FIGURE 4. Optimum sections with longitudinals.

With the condition $x=0$ when $y=0$ and $x=a$ when $y=b$, we therefore have,

$$\frac{x}{b}=\frac{1-k^2}{2k}\,\mathrm{F}\left(k,\frac{y}{b}\right) \quad . \quad . \quad (6)$$

$$\frac{a}{b}=\frac{1-k^2}{2k}\,\mathrm{K}. \quad . \quad . \quad . \quad (7)$$

Where $\mathrm{F}(k, y/b)$ is the elliptic integral of the first kind and K the complete elliptic integral, to modulus k.

It follows from (6) and (7) that

$$\frac{x}{a}=\frac{\mathrm{F}(k,y/b)}{\mathrm{K}}.$$

Typical curves can readily be plotted (with the aid of a table of elliptic functions) from (6) and (7) and this is done in Fig. 3 for three values of k^2.

We can deduce from (3) and (5) that

$$\frac{ds}{dx}=n-(n-1)(y/b)^2=-1+(n+1)\{1-k^2(y/b)^2\}$$

$$ds=-dx+(n+1)\{1-k^2(y/b)^2\}\,\frac{dx}{dy}\,dy$$

$$ds=-dx+\frac{b}{k}\sqrt{\frac{\{1-k^2(y/b)^2\}}{1-(y/b)^2}}\,d(y/b).$$

The solution to which is

$$s=-x+\frac{b}{k}\,\mathrm{E}(k,y/b) \quad . \quad . \quad (9)$$

where $\mathrm{E}(k, y/b)$ is the elliptic integral of the second kind and the distance s along the curve is measured from the origin. Hence.

$$L=-a+\frac{b}{k}\,\mathrm{E} \quad . \quad . \quad (10)$$

where E is the complete elliptic integral of the second kind. From (7) and (10)

$$\frac{L}{a}=\frac{2}{1-k^2}\,\frac{\mathrm{E}}{\mathrm{K}}-1. \quad . \quad . \quad (11)$$

In the original statement of the problem L and a were taken as known. Equation (11) enables us to deduce the value of k. From (7) we then obtain b and from (6)

the curve can be drawn. Fig. 5 gives the relation between L/a and k.

4. MOMENT OF INERTIA

The "moment of inertia" of one quadrant about the x=axis is

$$I=\int_0^L y^2 ds=\int_0^b y^2 \frac{ds}{dx}\frac{dx}{dy}dy. \qquad (12)$$

We can cast the results already obtained into the form

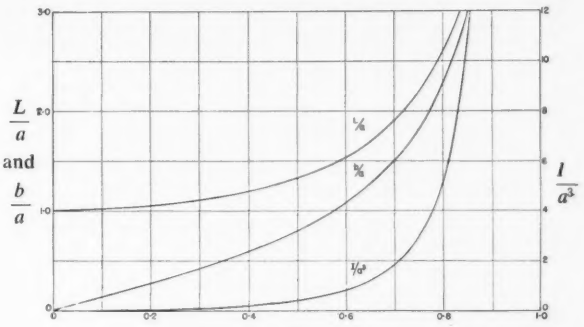
$$\frac{ds}{dx}=1+\frac{2k^2}{1-k^2}\left(1-\frac{y^2}{b^2}\right),$$

$$\frac{dx}{dy}=\frac{(1-k^2)/(2k)}{\sqrt{\left[\left(1-\frac{y^2}{b^2}\right)\left(1-k^2\frac{y^2}{b^2}\right)\right]}}.$$

Substituting these expressions in (12) and integrating with respect to y/b over the range 0 to 1, we obtain

$$\frac{I}{b^3}=\frac{1}{6k^3}\{(1+k^2)\mathrm{E}-(1-k^2)\mathrm{K}\}.$$

This is non-dimensional because I being the "moment of inertia" of an arc without thickness is of the third order in length.



L/a, b/a and I/a^3 against k.
FIGURE 5.

Using (7) we obtain

$$\frac{I}{a^3}=\frac{4}{3}\frac{1}{\{(1-k^2)\mathrm{K}\}^2}\left\{\frac{1+k^2}{1-k^2}\frac{\mathrm{E}}{\mathrm{K}}-1\right\}. \qquad (13)$$

Curves of L/a, b/a and I/a^3 are plotted against k in Fig. 5.

A Method of Rapidly Estimating Propeller Moment

by

P. R. PAYNE
(Auster Aircraft Ltd.)

PROPELLER MOMENT is the name given to a dynamic phenomenon which causes considerable trouble in the design of variable pitch propellers and helicopter rotors. The development of the fundamental equation has not previously been published, to the author's knowledge, and for this reason the steps leading up to it are given. The propeller moment on any section tends to place its major axis in the plane of rotation, and the fundamental equation is equation (5). Its use to determine the total moment at a blade root results in lengthy calculations, with the possibilities of delays and errors.

An analytical investigation is shown to result in an expression which gives an immediate answer for propeller moment, when two constants have been obtained from the data sheets (Figs. 4 and 5). The only limiting assumptions are that the rotor blade is linearly twisted and tapered.

NOTATION

Units are the Perry system, *i.e.* slugs (mass), lb. (force), ft., sec., radians.

dC.F. = centripetal force acting on elemental mass
δm = an elemental mass
w = rotational speed of rotor
r' = radial distance of element from hub centre
α = an angle defined in Fig. 1
z = chordwise distance of elemental mass from radial axis, relative to space axes
z' = value of z relative to section axes
y = dimension normal to z (Fig. 2)
y' = value of y relative to section axes
ΔM = propeller moment per unit length of blade
I_{minor}, I_{major} = second moments of mass of section about the z- and y-axes respectively
c = blade chord at any station
c_0 = theoretical root chord and hub
t = taper ratio = 1 − tip chord/root chord
x = blade station = r/R
R = overall blade radius
T = thickness of section at any station
T_{R} = section thickness at theoretical root section
τ = thickness taper ratio = 1 − tip thickness/root thickness

Received 28th February 1954.

θ = blade angle at any station

θ_R = blade angle at theoretical root section

θ_T = blade twist, root to tip

$I = I_{minor} - I_{major}$ (suffix R denotes value at root) (slugs ft.^{2}/ft. run)

x_1 = limiting inboard value of x at which blade terminates

$M_{C.F.}$ = total integrated propeller moment at root

THEORY

Considering the elemental mass shown in Figs. 1 and

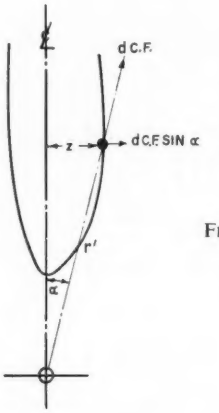


FIGURE 1.

2, the centripetal force acting on it is seen to be

$$dC.F. = \delta m w^2 r'.$$

The component of this normal to the radial axis is

$$dC.F. \sin\alpha = \delta m w^2 r' \sin\alpha$$
$$= \delta m w^2 z. \quad . \quad . \quad . \quad (1)$$

In Fig. 2 the z- and y-axis cross at the radial axis, which is normal to the plane of the paper. For ease of calculation, we assume this origin to coincide with the aerodynamic centre of the blade element. Then the moment exerted by the elemental mass about the axis of torsion is

$$dM = \delta m w^2 zy. \quad . \quad . \quad . \quad (2)$$

The total moment due to all the elemental masses in the section is

$$\Delta M = w^2 \int \delta m zy. \quad . \quad . \quad (3)$$

Referring to Fig. 3, we express x and y (relative to space axes) in terms of x' and y' which are relative to the section axes, and depend on its angle of incidence θ. The relationships are

$$\left.\begin{aligned} x &= \cos\theta\,(z' + y'\tan\theta) \\ y &= \cos\theta\,(y' - z'\tan\theta) \end{aligned}\right\} \quad . \quad . \quad (4)$$

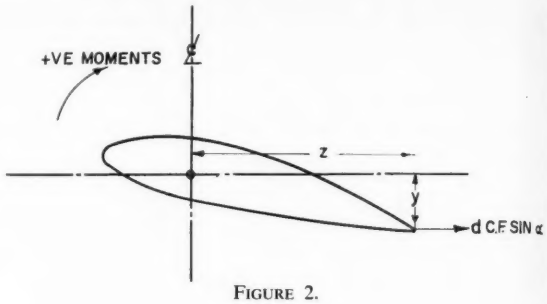


FIGURE 2.

Substituting in equation (3)

$$\Delta M = w^2 \int \delta m \cos^2\theta\,(y'^2 \tan\theta + z'y'(1 - \tan\theta) - z'^2 \tan\theta).$$

Since the section must be mass balanced about the aerodynamic centre, from flutter considerations

$$\delta m z' y' = 0.$$

Therefore the equation is simplified to

$$\Delta M = w^2 \int \delta m\,(y'^2 - z'^2)\cos^2\theta \tan\theta$$
$$= \tfrac{1}{2} w^2 \int \delta m\,(y'^2 - z'^2)\sin 2\theta$$
$$= -\tfrac{1}{2} w^2\,(I_{minor} - I_{major})\sin 2\theta. \quad . \quad (5)$$

In exact propeller moment calculations equation (5) is used directly. Values of moments of inertia per foot run are evaluated along the blade and substituted in the equation to give propeller moment per foot run. This is then graphically integrated to give the total propeller moment.

Such detailed calculations are not justifiable for the early stages of a design, and the following approximate

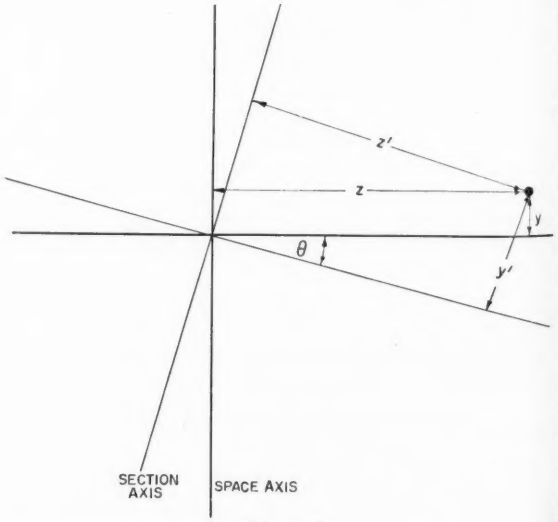


FIGURE 3.

analysis can be relied upon to give a fairly accurate value for total propeller moment at the root of a linearly twisted and tapered blade.

We assume

linear taper; $c=c_0(1-tx)$

linear thickness variation; $T=T_R(1-\tau x)$

linear twist; $\theta=\theta_R-\theta_T x$

constant constructional form; $I \propto \text{mass} \times \text{length}^2$
$=KTc^3$

where K is a constant.

Substituting for I, equation (5) becomes

$$-\Delta M=\tfrac{1}{2}w^2KTc^3\sin 2\theta.$$

Introducing the chord and thickness taper terms,

$$\begin{aligned}\frac{-\Delta M}{Kw^2c_0{}^3T_R}&=\theta_R-(3\theta_R t+\theta_R\tau+\theta_T)x+\\&+(3\theta_R t^2+3\theta_R t\tau+3\theta_T t+\theta_T\tau)x^2-\\&-(\theta_R t^3+3\theta_R t^2\tau+3\theta_T t^2+3\theta_T t\tau)x^3+\\&+(\theta_R t^3\tau+\theta_T t^3+3\theta_T t^2\tau)x^4-\\&-\theta_T t^3\tau x^5. \quad . \quad . \quad . \quad . \quad . \quad (6)\end{aligned}$$

The total propeller moment to be reacted at a station x will be

$$M_{C.F.}=R\int_{x_1}^{1\cdot0}\Delta M dx.$$

Neglecting powers of x_1 above $x_1{}^2$, as of negligible importance, we have

$$\begin{aligned}\frac{-M_{C.F.}}{KT_RRc_0{}^3w^2}&=\theta_R\left[(1-x_1)-(1-x_1{}^2)\left(\frac{3}{2}t+\frac{1}{2}\tau\right)+\right.\\&\left.+t\tau+t^2\left(1-\frac{3}{4}\tau\right)-t^3\left(\frac{1}{4}+\frac{1}{5}\tau\right)\right]-\\&-\theta_T\left[(1-x_1{}^2)+\frac{2}{3}\tau+2t\left(1-\frac{3}{4}\tau\right)-\right.\\&\left.-t^2\left(\frac{3}{2}-\frac{6}{5}\tau\right)+t^3\left(\frac{2}{5}-\frac{1}{3}\tau\right)\right] \quad (7)\\&=A\theta_R-B\theta_T \quad . \quad . \quad . \quad (8)\end{aligned}$$

where A and B are both functions of t and τ, and are given in Figs. 4 and 5.

Since $I_R=Kc_0{}^3T_R$, the left hand side can be written as

$$\frac{M_{C.F.}}{I_RRw^2}.$$

where $I_R=(I_{minor}-I_{major})$ at the theoretical root chord. In practice this is rather an abstract concept, and the value of I must be calculated for a typical section. If this typical value is I^* then

$$I_R=\frac{I^*}{(1-\tau x)(1-tx)^3}.$$

Knowing I_R, R and the rotational speed w, Figs. 4 and 5 can be used to give a rapid estimate for total propeller moment. These figures were calculated for a value of $x_1=0\cdot2$, which is a fairly typical value. Minor deviations will not materially affect the answer.

Possibly the two most valuable features of this method are that it enables for the first time a check to be made on the more precise but lengthy "graphical" calculations with equation (5); and secondly it enables an assessment of the problem to be made in the project stage, in order to choose the most satisfactory method of balancing the moment in the control system.

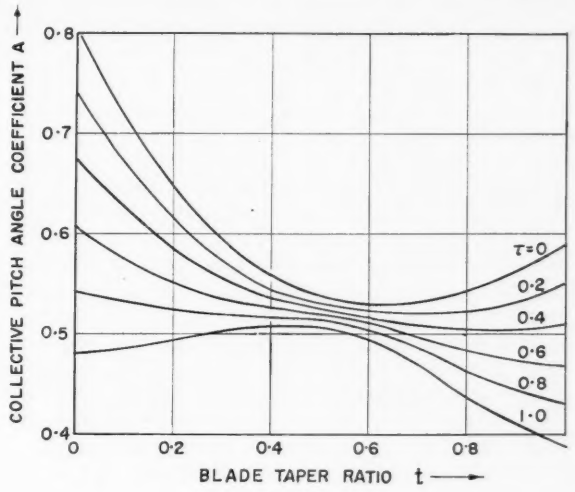


FIGURE 4.

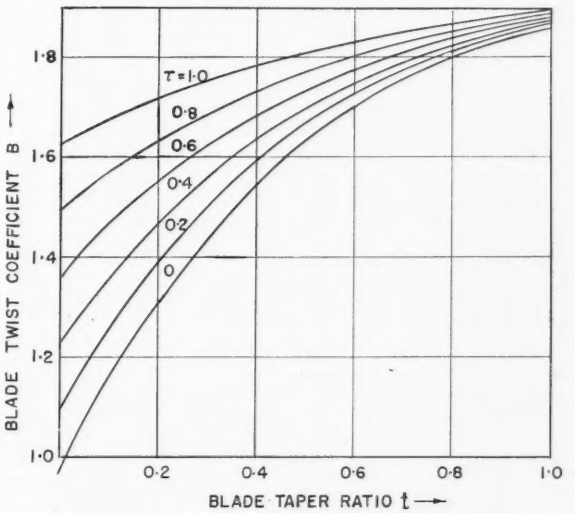


FIGURE 5.

A Method of Moment Distribution by Graphical Analysis

by

L. S. SRINATH, B.E., D.I.I.Sc.
(Blackburn and General Aircraft)

IN solving for the moments at the supports of a continuous beam, recourse is often made to Professor Hardy Cross's method when the number of supports is comparatively large. This paper describes a graphical method of moment distribution and it is proposed first to work out a specific problem by Cross's method, so that the validity of each step of the graphical method can be checked.

Figure 1 shows a beam supported at four points *A*, *B*, *C* and *D*. The loads acting on the beam are indicated in the figure.

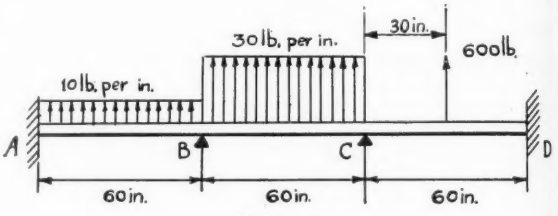


FIGURE 1.

MOMENT DISTRIBUTION

The solution by Hardy Cross's method is shown in Table I. The value of *EI* is constant throughout.

GRAPHICAL ANALYSIS

Considering each span as a fixed beam, the fixing moments are *AB*:—3,000 lb. in., 3,000 lb. in.; *BC*:—9,000 lb. in., 9,000 lb. in.; and *CD*:—4,500 lb. in., 4,500 lb. in.

The stiffness factor for each beam is calculated. Since the span *E* and *I* are constant for the three beams the values are the same.

In the middle of a sheet of graph paper a horizontal line is drawn to represent the beam (Fig. 2).

At the left hand end, *a*, a vertical line is drawn. A suitable distance is chosen from this point *a*, to represent the stiffness factor of the first span. As the stiffness factors are the same for each span, points *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i* and *j* are marked at equal intervals. The points *a* and *b* represent support *A*. Points *c*, *d* and *e* represent support *B*. Points *f*, *g* and *h* support *C* and points *i* and *j* support *D*. At support *A* the calculated moment was 3,000 lb. in. Mark this to a suitable scale as point 1 on the vertical line through *b*. At support *B*, there was an out-of-balance moment of 6,000 lb. in. given by the right hand side (R.H.S.). The line through *c* represents the L.H.S. of the support and the line through *e* represents the R.H.S. of the support (*see* Table I). On line *c* mark the point 1 to represent the zero moment (base line) and on the line *e* mark the point 1 to represent the out-of-balance moment of 6,000 lb. in. The points 1, 1 on *c* and *e* are marked within the support line *ce* (representing the support *B*). Similarly on the line *f* mark off 1 to represent the 4,500 lb. in. out-of-balance moment—offered by the L.H.S. of the support *C*. On the line *h*, point 1 is marked at the zero value on the base line. At support *D* there is a moment of 4,500 lb. in. and this is marked as 1 on *i*. The points 1 represent the out-of-balance condition at each support.

The first step in the moment distribution method was balancing. The point 1 on *b* (support *A*) needs no balancing. At support *B* (lines *c* and *e*) there is an out-of-balance moment of 6,000 lb. in. and this is distributed equally between the L.H.S. and the R.H.S. of the support. This is done graphically as follows. Join the points 1 on *c* and *e*, cutting the middle line *d* at some point *P*. Through *P* draw a horizontal line (on graph paper this can be easily drawn by a ruler with negligible error) to

TABLE I

	A	*B*		*C*		*D*
Fixed moments	+3000	+3000	+9000	+9000	+4500	+4500
1st Balancing	0	+3000	−3000	−2250	+2250	0
1st Carry-over	−1500	0	+1125	+1500	0	−1125
2nd Balancing	0	+562	−563	−750	+750	0
2nd Carry-over	−281	0	+375	+281	0	−375
3rd Balancing	0	+188	−187	−140	+141	0
3rd Carry-over	−94	0	+70	+94	0	−70
4th Balancing	0	+35	−35	−47	+47	0
4th Carry-over	−18	0	+24	+18	0	−24
5th Balancing	0	+12	−12	−9	+9	0
5th Carry-over	−6	0	+4	+6	0	−5
6th Balancing	0	+2	−2	−3	+3	0
6th Carry-over	−1	0	+1	+1	0	−1
Final moment	+1100	+6799	+6800	+7701	+7700	+2900

Originally received January 1954

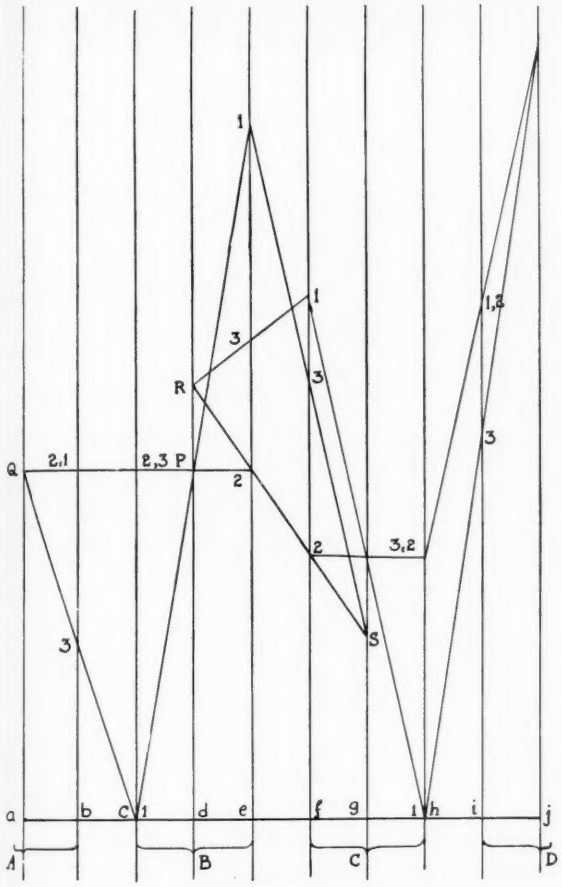


FIGURE 2.

cut the lines *c* and *e* at points 2. To the line *c* a moment equal to 1 – 2 is added and from the line *e* a moment equal to 1 – 2 is subtracted. So, the points 2, 2 refer to the balanced condition at the support *B*. At the support *C* (lines *f* and *h*) there is an out-of-balance moment of 4,500 lb. in. which is to be distributed equally. Join points 1, 1 cutting the middle line *g* at some point. Through this point draw a horizontal line to cut the lines *f* and *h* at points 2. These points represent the balanced condition for support *c*. At supports *A* and *D* no balancing operation was needed. So these points 1 are also denoted points 2, so as to correspond with the balancing condition.

The next step in the moment distribution was the carry-over operation. Half the balancing moment from the L.H.S. of support *B* is to be transferred (with a negative sign) to the support *A*. That is, half of 1 – 2 on line *c* is to be transferred to the line *b*. Since the balancing moment on *c* was an addition, the carry-over moment should be substracted from *b*. This is done graphically as follows. Join 2 on *c* to 2 on *b* and continue it to cut the line *a* at *Q*. Join *Q* to 1 on *c*, cutting the line *b* at 3. The point 3 marks the new moment on the line *b* and it is seen that it is below the point 2, indicating the subtraction of the moment. The fact that 2-3 on *b* is half of 1 – 2 on *c* is correct, as $ab = bc$. Similarly, half of 1 – 2 on *e* is to be transferred to the line *f* and half of 1 – 2 on *f* to be transferred to *e*. To do this, join the 2's on *e* and *f* and continue to meet the middle lines *d* and *g* at *R* and *S*. Join *R* and 1 on *f* to meet the line *e* at 3. As *de* is equal to *ef*, obviously 2 – 3 on *e* is half of 1 – 2 of *f*. Also, as 1 – 2 was subtracted on line *f*, half of this should be added to *e*. That this has been done can be seen from the figure. Similarly, by joining *S* to 1 on *e*, point 3 is obtained on *f*. The point 3 on *i* is obtained likewise. Throughout these carry-over operations, the sign convention is automatically followed. As no balancing was done on *b* and *i*, no moments are carried over to *c* or *h*, so these points 2 are also called points 3. Points 3 now represent the new out-of-balance position of the beam due to the carry-over moments.

The next operations are repetitions of these steps. The points 3 on *c* and *e* are joined to cut the middle line at some point. A horizontal through this point determines the points 4. Similarly, for the lines *f* and *h*. The

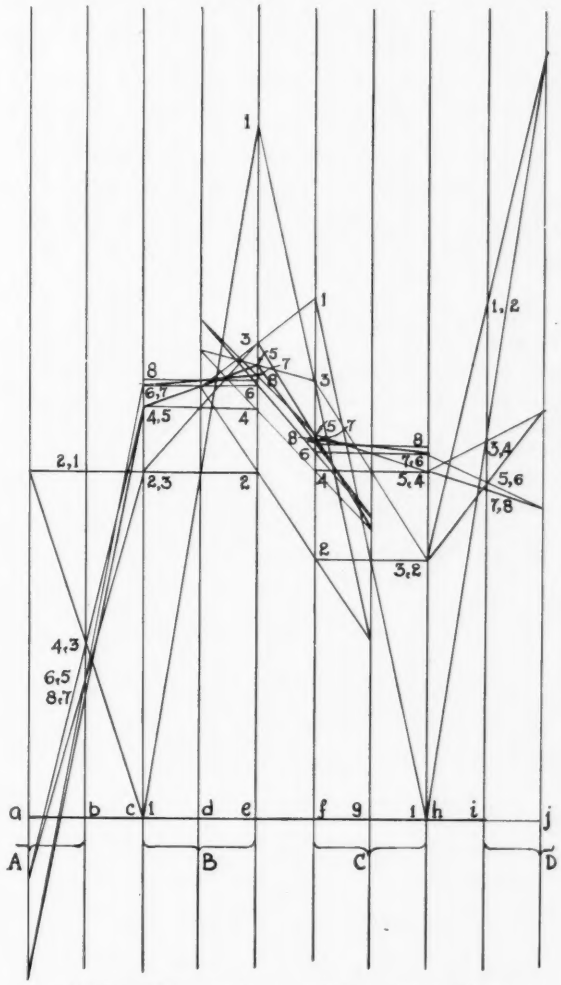


FIGURE 3.

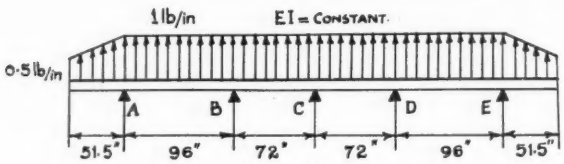


FIGURE 4.

next step is again the carry-over operation. This procedure is repeated until the points show a tendency to coalesce. The operations are shown in Fig. 3. The points 8 are the final moment positions. To these values of the moments (from the base line) the values of the original balanced moments are to be added. Thus, for support *A* the value from the figure is +1,100 lb. in. The original balanced moment was zero. Hence, the sum of these is +1,100 lb. in. For support *B*, from line *c* (or *e*) the value of the moments from the figure is +3,790 lb. in. and the original balance value was +3,000 lb. in. Hence, the sum of these is +6,790 lb. in. The value for support *C* is similarly 3,190+4,500=7,690 lb. in. For support *D* the final value is 2,910 lb. in.

In an actual case, the whole working of the operations takes very little time. The lines joining the points 2 and 3, and so on, need not be drawn at all as these points can be marked off directly. This is shown by a further example. This problem was a special one, since the value of *k* was assumed to be constant for each span. A general problem with different values for *k* is now considered.

A MORE GENERAL EXAMPLE

Figure 4 shows an elevator tube resting on five supports *A*, *B*, *C*, *D* and *E*. The value of *EI* is constant throughout. Because of the different lengths of span, the value of *k* will be different. For the first span (the overhang) $1/L=0{\cdot}0194=k_1$. For span *AB*, $k_2=1/96=0{\cdot}0104$.

The values of the stiffness factors ($\propto 1/L$) are shown in Table II. Because of the symmetry of the beam only one half will be considered. The values of the fixing moments are also shown. The first span being a cantilever beam, there is no need to fix it at both ends. The moment for this is only +883 lb. in. The out-of-balance moments are also shown.

On a sheet of graph paper, a horizontal base line is drawn to represent half of the beam. Let $1/51{\cdot}5=k_1$; $1/96=k_2$ and $1/72=k_3$. From the left hand end (*a*) mark off points *b*, *c*, *d*, *e*, *f*, *g*, *h* as follows (Fig. 5):—

$$ab=k_1;\ bc=k_2;\ cd=k_2;\ de=k_2;\ ef=k_3;$$

$$fg=k_3 \text{ and } gh=k_3.$$

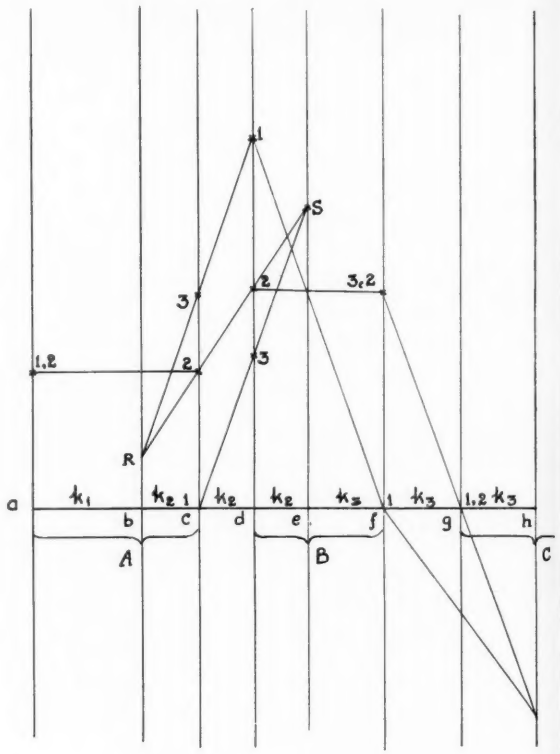


FIGURE 5.

In general the base line should be able to accommodate ($3\Sigma k$). Lines *a*, *b* and *c* represent support *A*. Lines *d*, *e* and *f* represent support *B*. Lines *g* and *h* represent half the support *C* (left hand side of *C*). If the symmetry of the supports is not taken into consideration, the base line can be extended to include points, such as *i*, *j*, *k*, *l*, and so on, to represent the other supports, but the whole diagram on the R.H.S. will be an image about the line *h*.

On line *a*, mark off 115 lb. in. to represent the out-of-balance between *a* and *c* (the L.H.S. and the R.H.S. of support *A*). On the line *C*, the point 1 is marked on the base line. Similarly, points 1 are marked on *d*, *f* and *g*. In the balancing operation the final moment at support *A* is 883 lb. in. as determined from the cantilever beam. Hence, point 1 on *a* is fixed and points 1, 3, 5, and so on, on *c* are always measured from this point as datum.

For balancing the support *B*:—If the support is out of balance by a moment *M* occurring at the L.H.S. of the support, then $Mk_2/(k_2+k_3)$ should be subtracted from the L.H.S. and $Mk_3/(k_2+k_3)$ should be added to the R.H.S. Here k_2 and k_3 are the stiffness factors of

TABLE II

	A		*B*		*C*		*D*		*E*	
Stiffness Factor $\propto 1/L=k$	0·0194	0·0104	0·0104	0·0139	0·0139	0·0139	0·0139	0·0104	0·0104	0·0194
Fixing Moments	+883	+768	+768	+432	+432	+432	+432	+768	+768	+883
Out-of-Balance Moments	+115	—	+336	—	—	—	—	+336	—	+115

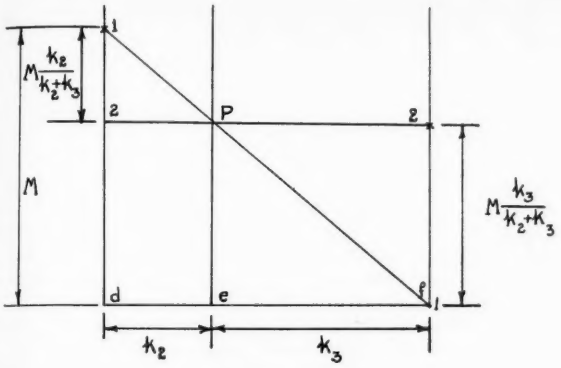


FIGURE 6.

the L.H.S. and R.H.S. spans of the support. Referring to Fig. 6, it can be seen how this is done. Points 1 are joined, cutting the middle line at *P*. A horizontal through this gives points 2. If $1-d$ is M, then $1-2$ on d is equal to $Mk_2/(k+k_2)$ and $2-f$ is equal to $Mk_3/(k_2+k_3)$. The former is subtracted from $1-d$, giving $2-d$, and the latter is added to $1-f$, giving $2-f$.

During the carry-over operation, since $bc=cd=k_2$, the value of $2-3$ on c is half the value $1-2$ on d (Fig. 5). Points 3 are obtained as before. Join 2 on c to 2 on d and produce on either side to cut the middle lines b and e at points *R* and *S*. Join *R* to 1 on d, cutting line c at 3. Join *S* to 1 on c giving 3 on d. As pointed out before, no lines need be drawn; the points may be marked off with a ruler.

The complete diagram is shown in Fig. 7. The final values of the moments are:—

Support $A=+883$ lb. in. = Support E
Support $B=+610$ lb. in. = Support D
Support $C=+344$ lb. in. = Support C

Partial fixity:—If any one of the supports is not firmly fixed (as is very common in aircraft structures), the same operations may be carried out with a suitable

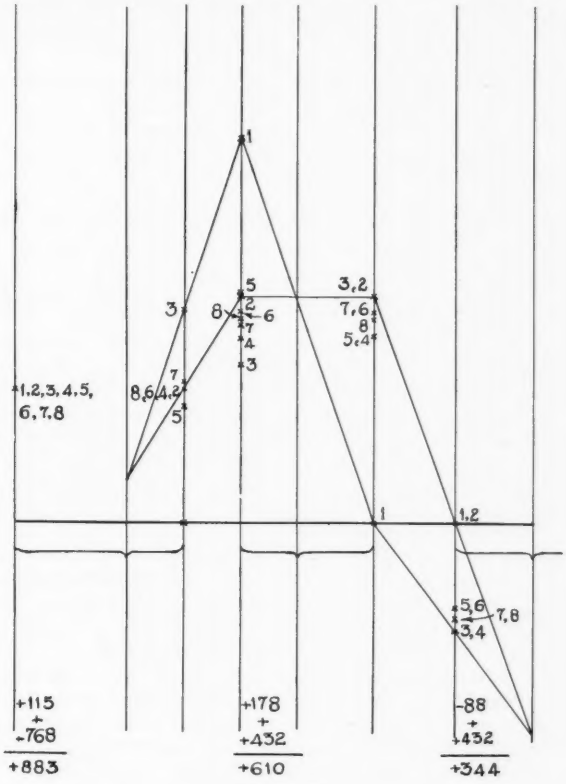


FIGURE 7.

value for the corresponding k. For example, if the support *C* is 50 per cent. fixed, the moment at *C* has to be balanced, as the support can take only half the value. This can be done by drawing a line i at a distance k_3 and starting with 1 on that line with zero value. The rest of the procedure remains the same. Previously there was no carry-over moment from g to f, but now there is.

*Receptances in Mechanical Systems**

WE WISH TO PROPOSE that the word "receptance" should be used instead of "admittance" as applied to mechanical systems (*see* R. and M. 2,000, 1947). By this, we mean that if a generalised disturbing force $F_s e^{i\omega t}$ is applied at the s^{th} generalised co-ordinate q_s of a linear oscillatory system, then the response at the r^{th} generalised co-ordinate is given by

$$q_r = \alpha_{rs} F_s e^{i\omega t}$$

where α_{rs} is the "Cross-receptance" between q_r and q_s. If $r=s$, then α_{rs} would be the "direct receptance" at q_s.

The reason for proposing this change is that there is a possibility of confusion between "admittances" as applied to mechanical and electrical systems. The two uses of the word have related, but not identical, origins.

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*This suggestion has also been sent to the Institution of Mechanical Engineers and to *Applied Mechanics Review*.

Received 18th March 1954.

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Reviews

ENGINEERING STEELS. *Leslie Aitchison and William Pumphrey. Macdonald and Evans, London 1953. 923 pp. Diagrams, Photographs and Tables. 105s. net.*

This is a book which will be highly valued by engineer and metallurgist alike.

It covers the subject of steel completely and while the main objective is to acquaint the engineer with the properties of steels and how to understand and use these properties, there is an extensive background of information on steel melting, heat treatment, casting, welding, brazing, and fabrication which adds enormously to its value.

The section on heat treatment is particularly interesting since it includes a detailed explanation of isothermal transformations, a study of which can contribute so much to the understanding of the heat treatment phenomenon.

The subject of hardenability is dealt with in some detail and the approach to this includes the American attitude which tends perhaps to be rather more specific than that in this country. The need for the conservation of alloying elements has brought the subject of hardenability very much to the fore during recent years.

The properties of steels are covered in complete fashion and this section includes considerable information on creep, a subject of ever increasing interest to the engineer and metallurgist engaged on turbine engine work.

In presenting this review of creep and creep testing the authors have rightly included references to various shortened methods of arriving at creep data. They have, however, warned the reader that for many purposes only that data obtained from long time test is satisfactory.

Other mechanical properties dealt with include tensile, impact, hardness and fatigue testing. The relative importance of the 0·1 per cent. proof strength and the fatigue value as applied to statically and dynamically loaded parts is well explained. The increasing use of steel castings has been reflected in an excellent chapter on this subject and it includes some sound advice to designers on how to design for castings. One of the more important chapters is that devoted to welding and brazing. There is an increasing tendency among engineers to fabricate parts from welded assemblies and the description of the various welding operations and the associated problems and difficulties should be invaluable to readers.

The book ends with a chapter called " The heart of the matter." This section should be read in detail by all engineers and metallurgists since it does get down to the fundamental facts about material quality. The authors state that an analysis of failures has shown that 90 per cent. are due to design and 10 per cent to material. After dealing with the all important stress raisers arising from design the authors proceed to discuss the metallurgical stress raisers and the heterogeneity of steel in general. There is a very sound discourse on the subject of ductility and of the need for high quality both in material and in manufacture when using materials of high tensile strength.

A study of this section by the engineer should help him to appreciate that it can be dangerous to take the properties of steel as shown by a simple test piece and to apply those properties without further thought to a complex component. There is a factor of ignorance in metals as well as in design.

" Engineering Steels " is a monumental volume packed with a vast amount of information on steels and will be read and re-read by metallurgists and engineers for many years to come.—E. R. GADD.

MECHANICAL VIBRATION. *G. W. Yan Santen. Philips' Technical Library, 1953. 296 pp. Illustrated. 35s. net.*

This book is one of the Philips' Technical Library and is a translation from the Dutch. The author is attached to the Measuring Equipment Division of Philips' Industries Ltd., and therefore it is not surprising that his treatment of the subject follows a practical bent, or that he includes some very useful chapters on the technique of vibration measurement. In these the elementary principles of vibration pick-ups and mechano-electrical transducers are discussed, and examples are quoted from the range of such instruments produced commercially by the Philips' concern. It is perhaps the inclusion of this matter, and also that of an interesting account of the analogies between mechanical and electrical oscillations, which will serve most to distinguish this book from other works of similar title. For the rest, the treatment follows much the usual pattern for an introduction to the theory of mechanical vibrations. It is a pity, however, that no mention is made of Rayleigh's method, and that more space is not given to the general problem of calculating resonance modes and frequencies of structures with non-uniform distribution of mass and stiffness.

Metric units only are used, but this would not confuse the English reader if, as indeed is mostly the case in this book, the equations are given in their correct dimensionally-consistent form so that any consistent set of units may be applied. A few of the equations quoted are not correct dimensionally. In most of these the metric units to be used are specified, but in equation (53) a factor g/π^2 is omitted, perhaps because g/π^2 is close to unity with g expressed in metres per second. Further, it does not help the English student when, as in Table V, dimensionally-consistent formulæ are quoted, but the reader is instructed to express lengths in centimetres.

The attractive dust cover shows illustrations of an aircraft and a bridge. The expectant aeronautical or structural engineer will therefore be disappointed to find that little or no space is devoted to the vibrations of these particular structures. There is, however, a section on aerodynamic sources of vibration with brief mention of buffeting and a not altogether satisfactory attempt at a physical description of the cause and prevention of aircraft flutter.

To sum up, here is a useful elementary introduction to the subject of mechanical vibrations, which can also serve as a reference book for some of the standard results of vibration theory. With a few exceptions, some of which are mentioned above, the reviewer found the exposition clear and the translation adequate. The book is well produced and fully illustrated, but a few printer's errors have been noted.—R. SCRUTON.

ULTRA HIGH FREQUENCY PROPAGATION. *Henry R. Reed and Carl M. Russell. Chapman & Hall 1953. 562 pp. Diagrams. 76s. net.*

Although the post-war years have seen quite a number of new books dealing with radio-propagation and -aerials the field is so extensive and so actively explored that there is plenty of room for authors who present fresh information and fresh viewpoints. Professor Reed of the University of Maryland and Mr. Russell of the U.S.N.A.T.C. have done this, giving a considerable amount of experimental material apparently obtained at the N.A.T.C. and putting particular emphasis on system design, as well as covering

the basic physics and technology of tropospheric propagation, aerial diagrams, array design and so on. The text is not strictly confined to the scope of the title but the chief practical interest is in the wave-range that extends from the upper region of the centimetric band to wavelengths of the order of 3 or 4 metres with which the possibility of ionospheric difficulties may usually be ignored. A considerable portion of the discussion is concerned with air-to-air and air-to-ground propagation-paths and systems and this will be of value to professional radio-engineers, radio-students and others engaged in the applications of radio to aeronautics, particularly for communications; radar receives only passing mention but the fundamental physics given is, of course, applicable to this.

The chapter headings are: 1. An introduction to U.H.F. communications and the system concept. 2. General aspects of propagation. 3. Meteorological theory. 4. Antennas and radiation phenomena (ground reflection behaviour). 5. Multipath propagation (ground-to-air, air-to-ground and ground-to-ground propagation). 6. Comparison of V.H.F. and U.H.F. propagation, dipole to dipole (ground-to-air and air-to-ground propagation). 7. Complex antennas (linear arrays). 8. Complex antennas (circularly polarised antennas). 9. System comparison, operation, and design of U.H.F. complex antennas. 10. Air-to-air propagation. 11. Lobe modulation interference and design considerations. 12. Effects of meteorological conditions on experimental flight data. 13. General operational considerations. 14. Illustrative systems design problems. Problems (without answers) are appended to Chaps. 2-14.

Bibliographic references to published work are so sparse as to be of little or no value and the indexing is poor. Apart from the tail-cap aerial, there appears to be no discussion of, or information on, some ingenious ideas for suppression of aircraft-aerials that have been publicised in recent years.—L. W. MEYER.

AN INTRODUCTION TO LIQUID PROPELLANT ROCKET ENGINEERING. *D. A. Parish. The Association of Engineering and Shipbuilding Draughtsmen. 44 pp. Illustrated. 3s. net.*

A pamphlet which defines the terminology and describes the fundamentals of liquid propellant rocket motors. The main sections are: (i) General theory including basic thermodynamics. (ii) Propellants. (iii) The rocket motor. (iv) Propellant supply systems. (v) Testing.

The pamphlet, as its title states, is an introduction to the subject and would be of little practical value to those engaged in the problems of the design of rocket motors. Other than on the subject of propellants, little useable design data is given.—J.D.

Additions to the Library

Abraham, M. and R. Becker. CLASSICAL THEORY OF ELECTRICITY AND MAGNETISM. 2nd edition. Blackie. 1950.

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Society of Automotive Engineers. SYMPOSIUM: ADHESIVES AND SEALANTS IN AIRCRAFT APPLICATIONS. S.A.E. 1953.

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Reports

AERODYNAMICS

Boundary Layer

*Calculation of the temperature field for incompressible laminar boundary-layer flow with and without pressure gradient. J. A. Zaat. N.L.L. Report F.*130.

This report describes some examples of the theory given in report F.127. A short survey of this theory is given, which deals with the velocity field as well as the temperature field with and without heat transfer at the wall for two-dimensional, incompressible, laminar boundary-layer flow with a pressure gradient. As far as possible the results of the calculations are compared with exact values and with measurements.—(1.1.1 × 1.9.1).

A flight investigation of the practical problems associated with porous-leading-edge suction. Paul A. Hunter and Harold I. Johnson. N.A.C.A. T.N. 3062 (*February* 1954).

This investigation was concerned with the effect of atmospheric dust and rain on the clogging of the porous leading edge, power requirements, and construction details. In the course of the investigation, the extent of porous area was varied to determine the effect on power requirements and maximum lift coefficients.—(1.1.5).

Present status of information relative to the prediction of shock-induced boundary-layer separation. Roy H. Lange. N.A.C.A. T.N. 3065 (*February* 1954).

The present status of available information relative to the prediction of shock-induced boundary-layer separation is discussed. Experimental results showing the effects of Reynolds number and Mach number on the separation of both laminar and turbulent boundary layers are given and compared with results obtained by available methods for predicting separation. The flow phenomena associated with separation caused by forward-facing steps, wedges, and incident shock waves are discussed. Applications of the flat-plate data to problems of separation on spoilers, diffusers, and scoop inlets are indicated for turbulent boundary layers.—(1.1.4.4).

Experimental investigation at a Mach number of 2.41 *of average skin-friction coefficients and velocity profiles for laminar and turbulent boundary layers and an assessment of probe effects. Robert M. O'Donnell. N.A.C.A. T.N.* 3122 (*January* 1954).

Average skin-friction coefficients for laminar and turbulent flows were measured on a hollow cylinder at a Mach number of 2·41 and over a Reynolds number range from $0{\cdot}06 \times 10^6$ to $0{\cdot}95 \times 10^5$ per inch. Comparisons with various laminar- and turbulent-boundary layer theories are presented, together with an assessment of probe effects.—(1.1.0.4).

Method for calculation of compressible laminar boundary layer with axial pressure gradient and heat transfer. Paul A. Libby and Morris Morduchow. N.A.C.A. T.N. 3157 (*January* 1954).

A rapid and sufficiently accurate method, for most practical purposes, of determining laminar-boundary-layer characteristics in flow with a given free-stream Mach number and given velocity distribution at the edge of the boundary layer is presented. The method can be easily applied to flow with zero pressure gradient for any (constant) Prandtl number of the order of unity and any given temperature distribution along the wall. For flow in an axial pressure gradient, the method can be applied for a Prandtl number of unity and any given uniform wall temperature.—(1.1.1).

Fluid Dynamics

Correlations involving pressure fluctuations in homogeneous turbulence. Mahinder S. Uberoi. N.A.C.A. T.N. 3116 (*January* 1954).

It is shown that the correlation of fluctuating static pressure (in an incompressible and homogeneous turbulence) with any fluctuating quantity in the flow field can be expressed in terms of the correlation of the same quantity with two or more components of the velocity. The correlations of pressure with itself and of pressure with two velocity components are investigated in detail for the case of isotropic turbulence.—(1.4.2).

Internal Flow

Effect of surface roughness over the downstream region of a 23° *conical diffuser. Jerome Persh and Bruce M. Bailey. N.A.C.A. T.N.* 3066 (1954).

An experimental investigation was conducted to determine the effect of increasing the extent of surface roughness over the downstream region of a 23° conical diffuser with a 2:1 ratio of exit to inlet area and with a constant-area tailpipe approximately 3-1/2 inlet diameters in length. The inlet-boundary-layer thickness was of the order of 5 per cent. of the inlet diameter. The air flows used in this investigation cover an inlet Mach number range from about 0·10 to 0·40, corresponding to Reynolds numbers of approximately 1×10^6 to 4×10^6 based on inlet diameter.—(1.5.1).

Effect of various arrangements of triangular ledges on the performance of a 23° *conical diffuser at subsonic Mach numbers. Jerome Persh and Bruce M. Bailey. N.A.C.A. T.N.* 3123 (*January* 1954).

An experimental investigation was conducted to determine the effect of rough and smooth triangular ledges, approximately one-tenth of the inlet boundary layer thickness in height, on the performance of a 23° conical diffuser with a 2:1 ratio of exit to inlet area and with a constant-area tailpipe about 3-1/2 inlet diameters in length. The inlet boundary-layer thickness was of the order of 5 per cent. of the inlet diameter. The air flows used in this investigation covered an inlet Mach number range from about 0·10 to 0·40, corresponding to Reynolds numbers from approximately 1×10^6 to 4×10^6 based on inlet diameter.—(1.5.1.1).

Stability and Control

A method for estimating variations in the roots of the lateral-stability quartic due to changes in mass and aerodynamic parameters of an airplane. Ordway B. Gates and C. H. Woodling. N.A.C.A. T.N. 3134 (*January* 1954).

Expressions are presented from which can be calculated the rates of change of the roots of the lateral-stability quartic with respect to the mass and aerodynamic parameters of an aeroplane. Results obtained from these expressions are compared with the results of exact calculations. The expressions are shown to have a definite relationship to the amplitude coefficients of the lateral modes of motion subsequent to input moments or forces.—(1.8.1).

Investigation of mutual interference effects of several vertical-tail-fuselage configurations in sideslip. William H. Michael. N.A.C.A. T.N. 3135 (*January* 1954).

This report presents results of sideslip tests made on three circular-arc fuselages and nine unswept vertical tails to determine the mutual interference effects between fuselages and vertical tails. The analysis shows the primary factors affecting the magnitude of the interference effects and the relative magnitudes of the induced loadings on the fuselage and on the vertical tail. Some observations concerning the distribution of the induced loadings are made. Some theoretical calculations of the interference effect of a body on adjacent lifting surfaces are included and compared with the experimental results.—(1.8.1.2).

Thermo-aerodynamics

See also Boundary Layer

Use of aerodynamic heating to provide thrust by vaporization of surface coolants. W. E. Moeckel. N.A.C.A. T.N. 3140 (*February* 1954).

The thrust and specific impulse obtainable by use of aerodynamic heating to vaporise aircraft surface coolants are determined as a function of Mach number for a variety of

NOTE:—*The figures in parentheses at the end of each Summary are for office use only.*

possible coolants. Use of hydrogen vaporisation as an independent propulsion system yields specific impulses comparable with those of current rocket propellants at very high Mach numbers. For use as an auxiliary power source, coolant vaporisation can produce specific impulses comparable with those of current rocket propellants at all Mach numbers.—(1.9.1 × 27.3).

Wings and Aerofoils

Span load distributions resulting from constant vertical acceleration for thin sweptback tapered wings with streamwise tips. Supersonic leading and trailing edges. Isabella J. Cole and K. Margolis. N.A.C.A. T.N. 3120 (*January* 1954).

On the basis of the linearised supersonic-flow theory, equations for the span load distribution resulting from constant vertical acceleration (i.e. linear angle-of-attack variation with time) are derived for a series of thin sweptback tapered wings with streamwise tips. The analysis is valid, in general, at Mach numbers for which the wing leading and trailing edges are supersonic. Computational results are presented in the form of generalised design curves which permit fairly rapid estimation of the load distribution for broad ranges of the parameters aspect ratio, taper ratio, leading-edge sweepback, and Mach number.—(1.10.1.2).

On the kernel function of the integral equation relating the lift and downwash distributions of oscillating finite wings in subsonic flow. C. E. Watkins, H. L. Runyan and D. S. Woolston. N.A.C.A. T.N. 3131 (*January* 1954).

The kernel function of an integral equation relating the downwash to the lift distribution of a finite wing oscillating in subsonic compressible flow is treated. The kernel is reduced to a form which is amenable to calculations and the types of singularities are shown. As a check, it is shown that the kernel for the three-dimensional case reduces exactly to the known kernel for the two-dimensional case. In addition, results for the special cases of Mach number of 0 (incompressible case) and frequency of 0 (steady case) are given.—(1.10.1.2).

Testing and Instruments

The Ames 10- *by* 14-*inch supersonic wind tunnel. A. J. Eggers, Jr. and George J. Nothwang. N.A.C.A. T.N.* 3095 (*January* 1954).

The Ames 10- by 14-inch supersonic wind tunnel is described and pertinent features of the design and operation of the facility are included. The wind tunnel is capable of continuous operation at Mach numbers from 2·7 to 6·3 and Reynolds numbers from 1 million to 11 million per foot. Data on the characteristics of flow in the test section, including pressure and stream-angle distributions, are presented.—(1.12.1).

Density profiles of subsonic boundary layers on a flat plate determined by X-ray and pressure measurements. Ruth N. Weltmann and Perry W. Kuhns. N.A.C.A. T.N. 3098 (*February* 1954).

Laminar, transitional, and turbulent boundary layers were investigated in a subsonic wind tunnel at Mach numbers of 0·55 and 0·78 at various Reynolds numbers and stations along a flat plate. Comparisons are made of the density profiles obtained with a total-pressure probe of small frontal opening and by means of an X-ray absorption method and, in a few cases, by using interferometer data. The limitations of the probe and X-ray methods are discussed.—(1.12.1 × 1.1).

Flight investigation at large angles of attack of the static-pressure errors of a service pitot-static tube having a modified orifice configuration. William Gracey and Elwood F. Scheithauer. N.A.C.A. T.N. 3159 (*February* 1954).

The static-pressure errors of two essentially similar service pitot-static tubes and of three modified orifice arrangements on one of these tubes have been determined from flight tests over a range of angle of attack α of $-15°$ to $45°$, at Mach numbers from 0·20 to 0·68 and at Reynolds numbers from $0{\cdot}9 \times 10^5$ to $2{\cdot}7 \times 10^5$ (where Reynolds number is based on local velocity and the diameter of the tube).—(1.12.2).

AEROELASTICITY

See also Structures: Theory and Analysis

The effect of sweepback on the fundamental derivative coefficient for flexural motion. J. B. Bratt and K. C. Wight. R. & M. 2774 (*October* 1950, *published* 1953).

Measurements have been made with new equipment, designed for derivative tests in a 9 × 7 ft. tunnel, to determine the effect of sweepback on the derivatives $\lambda\dot{\phi}$ and $\lambda\phi$ for a rectangular aerofoil of aspect ratio 6.—(2).

The plane problem of the flapping wing. Walter Birnbaum. N.A.C.A. Technical Memorandum 1364 (*January* 1954).

A theoretical study, based on vortex theory as applied to the linearised equations of motion, is made of the air forces on wings of infinite aspect ratio in incompressible flow. Expressions for forces and moments associated with steady harmonic oscillations in vertical translation and pitching of wings are derived in the form of power series in terms of a reduced frequency parameter. Use is made of the derived forces first to treat the problem of propulsion due to wing flapping and second to determine theoretical flutter speeds of some simple spring mounted configurations.—(2 × 1.10.1.2).

AIRCRAFT OPERATION

Some additional notes on the derivation of airworthiness performance climb standards. A. K. Weaver. R. & M. 2769 (*February* 1950, *published* 1953).

After the publication of a report (R. & M. 2631) on the derivation of airworthiness performance climb standards, various subsidiary points raised in the course of discussions were examined. Some of these have been collected together in the present note. They are in the nature of elaborations of the original method and include a refined method of deriving the take-off climb standard, a method of treating interdependence of engine failure and a method for including the effect of sideslip in the margin allowed for pilotage errors. The main principles set forth in the earlier report remain unaffected.—(5.3).

ELECTRONICS

A waveform generator. R. J. Harron. N.A.E. Canada, Laboratory Report LR-80 (*October* 1953).

The instrument described in this report is capable of generating any desired waveform at recurrent frequencies between two and seventy cycles per second. An outline of the desired waveform is cut from a sheet of opaque material and inserted in a slot located between a phototube and a cathode-ray tube. The output voltage is dependent on the height of the waveform mask, and reaches a maximum of eighty volts peak to peak across an internal impedance of ten thousand ohms.—(11).

FLIGHT TESTING

A photographic method for determining vertical velocities of aircraft immediately prior to landing. Emanuel Rind. N.A.C.A. T.N. 3050 (*January* 1954).

A photographic method which has been successfully used for obtaining statistical data on vertical velocities of land-based aircraft immediately prior to landing contact is described. A long-focal-length (40-inch) lens is used. No instrument installation on the aircraft or interference with airport operation is required. A relatively simple data reduction is employed.—(13).

FUELS AND LUBRICANTS

Lubricants of reduced flammability. Charles E. Frank, Donald E. Swarts and Kenneth T. Mecklenborg. N.A.C.A. T.N. 3117 (*January* 1954).

Determination of the change in spontaneous ignition temperature with composition for blends of hydrogenated polyisobutylene with typical ester, hydrocarbon, and polyether lubricants has shown that 40 per cent. hydrogenated polyisobutylene by volume raises the ignition temperature of these lubricants by 60° to 80°C.—(14.3).

STRUCTURES

Loads

An investigation of high-altitude clear-air turbulence over Europe using Mosquito Aircraft. G. S. Hislop and D. M. Davies. R. & M. 2737 (*June* 1950, *published* 1953).

The British European Airways Clear-Air Gust Research Unit was formed, with the financial support of the Ministry of Supply, to investigate the problem of clear-air turbulence at high altitude over Europe. The aircraft were based at Cranfield, Bedfordshire, and flights were made of roughly 1,000 miles radius from that base. In the two years of its existence, the two PR 34 Mosquito aircraft employed for the purpose covered 92,300 miles of research flying between the selected limits of 15,000 ft. and 37,000 ft. Statistically speaking this is a very small sample and must be borne in mind when considering results. Some twenty areas of turbulence (defined as giving vertical acceleration increments greater than $\pm 0{\cdot}2g$) were actually investigated, the greatest vertical gust velocity encountered being +26 ft./sec. E.A.S. The results were examined from the passenger comfort and structural aspect, and from the meteorological aspect.—(33.1.1 × 24).

Resonant vibration of helicopter rotor blades. J. Morris. R. & M. 2801 (*June* 1950, *published* 1954).

The blades of the operative rotors of helicopters are usually hinged both in the lift and rotational planes and it is because of this articulation that the blades in the course of rotation are akin dynamically to "pendulum vibration dampers." This paper discusses the serious resonant forced vibration which may ensue when the fundamental frequency of this species of pendulum vibration is numerically equal to the product of the number of blades and the frequency of rotation of the rotor.—(33.1.2).

Theory and Analysis

*Torsional strength and stiffness tests of wing leading edges. J. F. Besseling and W. K. G. Floor. N.L.L. Report S.*421.

Torsion tests were carried out on 36 wing leading edges stiffened by full-web ribs only. N.A.C.A. 0009, 0012 and 0015 aerofoil sections with 3 closing web positions and 4 skin thicknesses were tested. The prebuckling torsional stiffness proved to agree well with the Batho-Bredt formula. An empirical formula is given for the ultimate strength and a comparison made with tests carried out elsewhere.—(33.2.3.1).

Elastic buckling under combined stresses of flat plates with integral waffle-like stiffening. Norris F. Dow, L. Ross Levin and John L. Troutman. N.A.C.A. T.N. 3059 (*January* 1954).

Theory and experiment were compared and found in good agreement for the elastic buckling under combined stresses of long flat plates with integral waffle-like stiffening in a variety of configurations.—(33.2.4.6.6).

Data on the compressive strength of skin-stringer panels of various materials. Norris F. Dow, William A. Hickman and B. Walter Rosen. N.A.C.A. T.N. 3064 (*January* 1954).

Flat skin-stringer compression panels of stainless steel, mild steel, titanium, copper, four aluminium alloys, and a magnesium alloy were tested. The results show the effect of variations in yield stress, Young's modulus, and both yield stress and Young's modulus for constant yield strain on the buckling, and load-shortening characteristics of the panels.—(33.2.4.6.6).

Analysis of sweptback wings on Cal-Tech analog computer. Richard H. MacNeal and Stanley U. Benscoter. N.A.C.A. T.N. 3115 (*January* 1954).

Using the Cal-Tech analog computer, structural analyses have been made of two 45° swept wings of aspect ratio 3. One of these has a constant depth and the other has a constant biconvex cross section in planes parallel to the air stream. The wings extend through the fuselage and are rigidly supported along two lines at the faces of the fuselage. Deflection and all internal forces have been calculated for concentrated static loads. Vibration modes are also presented.—(33.2.3.2 × 2).

Creep bending and buckling of linearly viscoelastic columns. Joseph Kempner. N.A.C.A. T.N. 3136 (*January* 1954).

The general dynamic equation of creep bending of a beam loaded laterally and axially was derived for a linearly viscoelastic material whose mechanical properties can be characterised by four parameters. The material can exhibit instantaneous and retarded elasticity as well as pure flow. The equation was used to determine creep characteristics of a beam in pure bending and a column with an initially sinusoidally deformed axis.—(33.2.2 × 33.2.4.2.1).

Creep bending and buckling of nonlinearly viscoelastic columns. Joseph Kempner. N.A.C.A. T.N. 3137 (*January* 1954).

Differential equations of bending of an idealised H-section beam column were derived for a non-linearly viscoelastic material whose mechanical properties are analogous to a model consisting of a linear spring in series with a non-linear dashpot whose strain rate is proportional to a power of the applied stress. The equations were used to obtain the creep-bending deflections of a beam in pure bending and of a column with initial sinusoidal deviation from straightness.—(33.2.2 × 33.2.4.2.1).

Creep buckling of columns. Joseph Kempner and Sharad A. Patel. N.A.C.A. T.N. 3138 (*January* 1954).

Formulas are presented for the determination of the creep deflection-time characteristics of an initially curved idealised H-section column. These results were obtained from closed-form solutions of the differential equation of bending (derived in N.A.C.A. T.N. 3137) of a beam column whose creep properties are of a non-linearly viscoelastic nature. The critical time (the time required for infinite deflections to develop) established by these solutions is tabulated and plotted for a wide range of the parameters involved.—(33.2.2 × 33.2.4.2.1).

Time-dependent buckling of a uniformly heated column. Nathan Ness. N.A.C.A. T.N. 3139 (*January* 1954).

A theoretical investigation is presented of the time-temperature-dependent buckling of a pin-jointed constant-section column, whose initial curvature is defined by a half-sine wave when the material is linearly viscoelastic and is heated uniformly along the column at a prescribed time rate.—(33.2.2 × 33.2.4.2.1).

A substitute-stringer approach for including shear-leg effects in box-beam vibrations. William W. Davenport and Edwin T. Kruszewski. N.A.C.A. T.N. 3158 (*January* 1954).

The use of the substitute-stringer approach for including shear-lag in the calculation of transverse modes and frequencies of box beams is discussed. Various thin-walled hollow rectangular beams of uniform wall thickness are idealised by means of the substitute-stringer approach and the resulting frequencies of the idealised structures are compared with those of the original beams. The results indicate how the substitute-stringer idealisation could be made in order to yield accurate representation of the shear-lag effect in dynamic analysis.—(33.2.4.1.2 × 2).

THERMODYNAMICS

Experimental determination of local and mean coefficients of heat transfer for turbulent flow in pipes. I. T. Aladyev. N.A.C.A. Technical Memorandum 1356 (*February* 1954).

Heat-transfer coefficients were determined for the flow of water through a heated pipe. The local heat-transfer coefficient was found to decrease along the length of the pipe up to a distance of about 40 diameters from the entrance. Equations are given for the local and mean heat-transfer coefficients as functions of the Reynolds number, Prandtl number, and length of the pipe in diameters.—(34.3).

APPOINTMENTS

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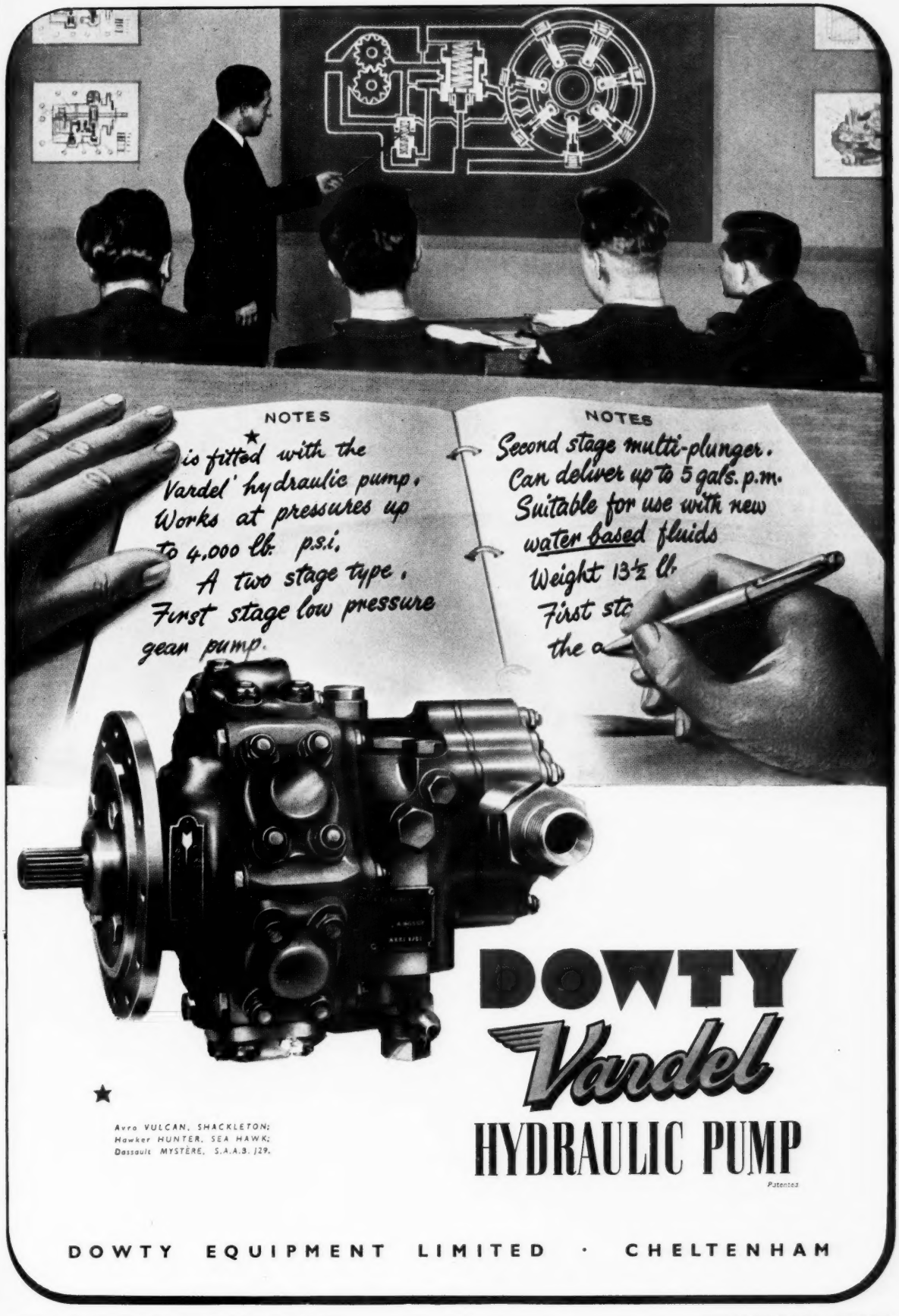
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